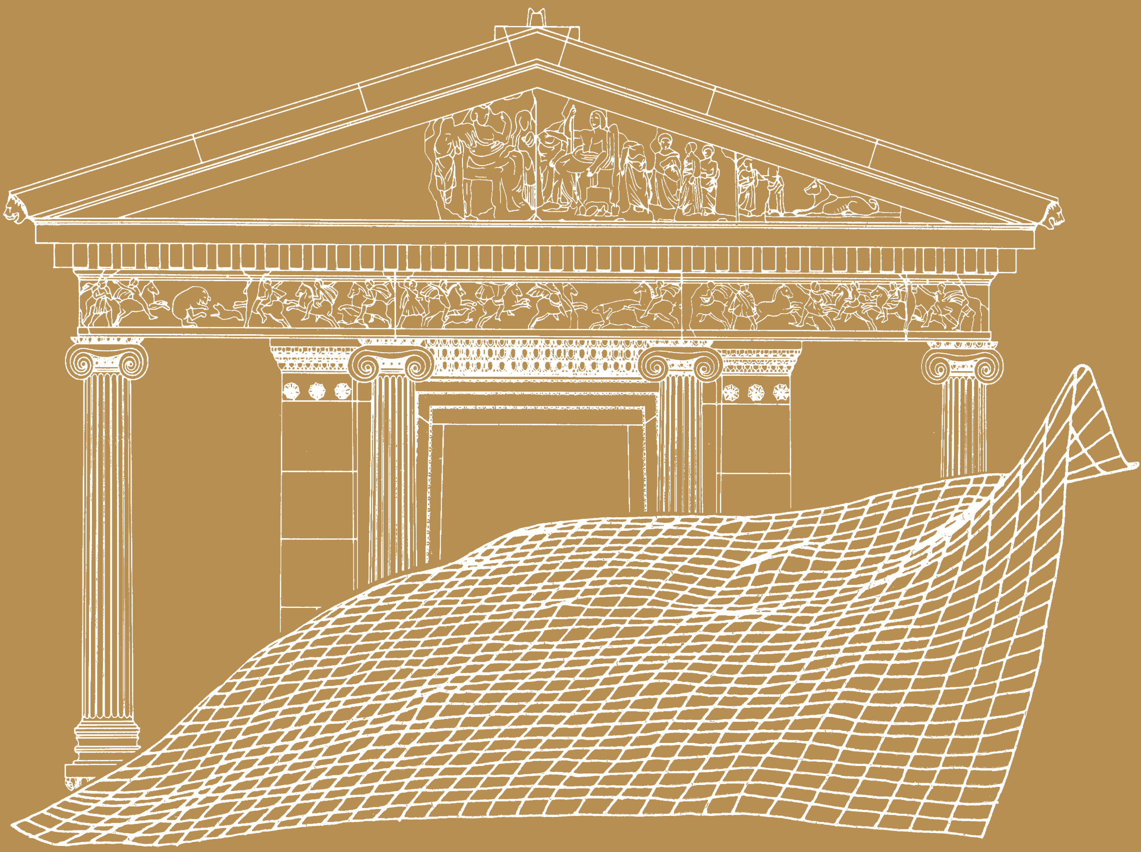

ARCHEOLOGIA E CALCOLATORI

34.2

2023

All'Insegna del Giglio

ARCHEOLOGIA E CALCOLATORI

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INDICE

IN RICORDO DI LEA FROSINI ARIANI,
UN EDITORE LUNGIMIRANTE

La notizia della scomparsa di Lea Frosini Ariani il 23 dicembre 2022, alla vigilia di Natale dello scorso anno, ci ha colti di sorpresa e ci ha lasciati smarriti di fronte alla perdita di una delle protagoniste della nascita e dello sviluppo editoriale di «Archeologia e Calcolatori».

La "Signora Lea", con la sua presenza costante, silenziosa ma rassicurante, è entrata nella storia della nostra rivista nel 1989, circa un decennio dopo il suo incontro con Riccardo Francovich e l'avvio di «Archeologia Medievale». La riunione per definire gli aspetti del nuovo progetto editoriale di una rivista internazionale dedicata all'informatica applicata all'archeologia riporta alla mente un'atmosfera di generale entusiasmo: le personalità volitive e dinamiche di Mauro Cristofani e di Riccardo Francovich, un gruppo di giovani studiosi a cui affidare la direzione e la redazione, un editore dotato al tempo stesso di professionalità e di umanità, pronto ad aprirsi ad ambiti meno noti ed esplorati del sapere, e un'ansia costruttiva di raccogliere presto i frutti di quanto si sarebbe seminato.

Ricordando Riccardo Francovich, Lea Frosini Ariani aveva voluto intitolare il suo saggio "A come Archeologia, A come Avventura", tenendo a precisare che il termine avventura non era genericamente legato alla professione dell'archeologo, quanto piuttosto al «partire alla ventura» di Francovich nell'«affidare la gestione di Archeologia Medievale ad una casa editrice nata da poco, quasi per gioco». Nel nostro caso, dopo solo un decennio, la situazione si era capovolta, perché le Edizioni All'Insegna del Giglio erano ormai una casa editrice affermata nel settore dell'archeologia, mentre la tematica da noi proposta costituiva per i Paesi europei gravitanti intorno al bacino del Mediterraneo, e in particolare per l'archeologia di epoca storica, un aspetto della ricerca ancora in fase embrionale. Se oggi volessimo ricalcare quel titolo, lo potremmo così concepire: "I come Informatica, I come Innovazione", dando a quest'ultimo termine anche una connotazione di Interdisciplinarità.

C'è un'altra delle tante tappe del percorso ultratrentennale di «Archeologia e Calcolatori» che giova ricordare a testimonianza della generale attenzione verso l'innovazione da parte di Lea Frosini Ariani e della sua solida convinzione che per lo sviluppo della scienza fosse necessaria una continua mediazione editoriale. Nel 2005, a soli due anni dalla Dichiarazione di Berlino sull'accesso aperto alla letteratura scientifica, la rivista, sempre pronta a sperimentare nuove vie di diffusione delle conoscenze, decise di aderire all'iniziativa proponendo un modello editoriale oggi noto con il nome di "diamond open access". Se tuttora si discute sulla fattibilità o meno di tale modello anche a livello europeo, dove proliferano infrastrutture e progetti dedicati a questa problematica, è eccezionale la lungimiranza che ha contraddistinto le Edizioni All'Insegna del Giglio. E ciò anche grazie al ruolo del figlio Tommaso, che Lea Frosini Ariani aveva chiamato ad affiancarla fin dalla fine degli anni Novanta, assai sensibile alle innovazioni del digitale e della comunicazione multimediale. Pare ancora incredibile aver trovato vent'anni fa una sponda proprio in un editore indipendente.

Per questo e per tanti altri ricordi di un lungo sodalizio scientifico e umano, la rivista «Archeologia e Calcolatori» si stringe con gratitudine e affetto nel ricordo della "Signora Lea", che è stata per tutti noi un esempio trainante di intelligente operosità e rigore.

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DEVELOPING A DIGITAL ARCHAEOLOGY CLASSIFICATION SYSTEM USING NATURAL LANGUAGE PROCESSING AND MACHINE LEARNING TECHNIQUES

1. The scientific background

This article draws on an interdisciplinary research project promoted in 2019 to enhance the contribution of the National Research Council of Italy in the field of Cultural Heritage by means of a comparative study with the leading Italian and international research players. The simultaneous establishment of the Institute of Heritage Science (ISPC), which represents today the CNR's hub for research, innovation, and technological transfer of the Cultural Heritage strategic area, made it possible to launch an attempt to systematically classify its main expertise. The study was entrusted to SIRIS Academic, a consulting company specialised in higher education and research policies, which has been involved for several years in the development of research portfolio analyses – as a means of characterising research, based on the semantic content of scientific production and research projects. Since existing classification systems (e.g. bibliometric categories) do not represent contemporary research (mainly multidisciplinary, challenge-based), new transversal approaches that directly explore the semantic content (e.g. titles, abstracts, summaries) of research outputs have been developed by SIRIS Academic using text mining methods. To this end, the company has cooperated with numerous universities, research centres, governmental bodies and research quality assessment agencies (see Zenodo SIRIS: https://zenodo.org/communities/siris-academic/).

The analysis of a large corpus of textual data of the ISPC, extracted from research and project activities, was conducted in collaboration with an interdisciplinary team of ISPC researchers (Caravale *et al.* 2021). The study was divided into two distinct, closely interrelated levels: a) identifying the research competences on Heritage Science within the CNR (including the ISPC), and b) comparing them with the competences at the national level, considering other research organisations (e.g. INFN, INGV, etc.) and universities.

The research process involved a set of successive steps, which started with the identification and extraction of CNR research projects and publications between 2010 and 2019 inclusive, using a controlled vocabulary (hereafter, VOC) for Cultural Heritage. A controlled vocabulary is an organised arrangement of words and phrases used to index content and/or to retrieve content through browsing or searching (Harping 2013). In other words, the goal of a VOC is to fully identify a specific research area/topic based on a given definition that can be adapted to a particular scope often difficult to find in traditional classification systems (e.g. Neuroscience, encompassing neurobiology, neurology, mental disorders, mental health/wellbeing and its social aspects). The specific perimeter of a VOC is established with field experts ahead of the analysis, to construct a conceptual map that defines the boundaries of a specific domain of interest. The presence of a term from the VOC (in title, abstract and/or author keywords), identifies the document as pertaining to the domain (Fuster, Massucci, Matusiak 2020).

The following were chosen as data sources: the Scopus citation database for publications; the CORDIS Community Research and Development Information Service for projects funded under the European Union's framework programmes (FP7 and H2020); and finally, the database of projects of the Creative Europe programme, all available in open format. As for ISPC, since the institute is significantly characterised by non-bibliometric research domains whose publications are often not indexed in international databases, information from PEOPLE, the CNR platform that hosts the institutional repository of research products, was added.

Data were also supplemented with information on the electronic resources stored in the repository of the CNR open access journal «Archeologia e Calcolatori» specialised in computational archaeology. During its 30-year publishing activity, the journal has classified articles using a dual taxonomy: the typology of computer applications to archaeology and the archaeological research fields largely involved in the application of computer methods. It could therefore serve as a well-established reference example of a scientific-academic classification implemented in a top-down approach by cross-domain experts and based on their knowledge of specific theoretical and methodological issues.

Of particular interest for its heuristic implications was the research phase addressed to content analysis and the identification of the most relevant topics dealt with in publications (topic modelling). Topic modelling is a machine learning technique that serves to automatically 'discover' the topics from a collection of texts. It is a bottom-up, automatic and unsupervised technique and is very useful for conducting an emerging analysis of research, technology and innovation ecosystems. This method applies to un- or semi-structured texts and makes it possible to identify on a statistical probabilistic basis the co-occurring lexical clusters (topics) that characterise a collection of documents and to analyse their distribution.

At this point, the intervention of experts becomes crucial: unsupervised machine learning methods are mainly used in the exploratory phase, when the aim is to extract from the data some otherwise not readily discernible structures and to highlight associations between topics sharing a common terminology but apparently unrelated. The re-classification and structuring of the results of this procedure, also in view of proposing interpretations and making predictions, is the task of the researchers, who should identify a model to guide and rule the investigation.

In examining the results, it was interesting to observe how the subject-specific topics recorded in the A&C classification were absorbed within the broader field of Cultural Heritage. The first factor that clearly emerged was that the specificity of individual research approaches featuring the field of digital archaeology is getting blurry, as records were largely merged into broader and more wide-ranging topics. For example, the marked preponderance of field research methods that emerges from the A&C classification resulted less evident, being distributed among different topics, from the more general 'Archaeological Research and Methods' to the more specific 'Geophysics, Digital Mapping and GIS', 'Photogrammetry, Image Processing and Digital Reconstruction' and 'Remote Sensing', which emphasise the technical-scientific aspect of the research though not including the more traditional closely humanistic one.

For this reason, it was decided to reconsider the analysis of the data extracted from the journal, by focusing precisely on the topic of digital archaeology with the specific aim of finding new ideas to supplement the classification which was first drafted over twenty years ago (Moscati 1999) and which has since followed the evolutionary course of the discipline (Cantone, Caravale 2019). This is the aim of the current study.

Digital archaeology contributes significantly to the more general scenario of Heritage Science, as evidenced by the laboratories of the Italian node of the E-RIHS infrastructure and by the activities recently promoted as part of the PNRR H2IOSC (Humanities and cultural Heritage Italian Open Science Cloud) project launched at the end of 2022. By stimulating the production of research perspectives that look to the past but are in line with the breakthrough development of science and technology (Moscati 2021), digital archaeology represents a specific research area, with a highly interdisciplinary character, supported by a long tradition of studies. At the same time, it forms an integral part of an innovative process of growth and development combining research, conservation, and scientific dissemination, in close relationship with the needs and requirements of today's information society.

2. Datasets

For the present analysis, we rely on two main datasets: the open access repository of «Archeologia e Calcolatori», which is registered in the list of OAI Data Providers (http://www.archcalc.cnr.it/oai/aec_oaipmh2.php) and the publications of the 'Computer Applications and Quantitative Methods in Archaeology' conference proceedings and journal. The first one is the focus of our analysis, whereas the latter is used as a benchmark for the former.

2.1 *A&C*

The data from publications in «Archeologia e Calcolatori» (A&C) – coming from both regular issues and Supplements – were provided directly by the editors of the journal and consist, most importantly, of their title, abstract, year of publication and affiliations of the authors. After some light data pre-processing (such as removal of records without much textual content, e.g. Introduction, Preface, etc.), and limiting ourselves to the period 2011-2020, the dataset counts with 477 records.

From a methodological point of view, the second decade of the new Millennium marks the consolidation of certain methods and the development of new ones. In the same period, from an editorial point of view, A&C witnessed the publication of as many as 9 conference proceedings (http://www.archcalc.cnr.it/pages/special_issues_proceedings.php) in addition to the regularly submitted articles. Furthermore, in 2019 a special issue was dedicated to the 30th anniversary of the journal (Moscati 2019). As for the Supplements, the data contains the 10 volumes published in the decade under investigation (http://www.archcalc.cnr.it/supplements/year_list_sup.php).

2.2 *CAA*

The publications in the 'Computer Applications and Quantitative Methods in Archaeology' conference proceedings and journal (CAA) constitute another long-standing observatory of key trends in computational archaeology, making it suitable as a benchmark for our study. The annual meetings originated in England in the 1970s and have grown over time, becoming today an international event open to large numbers of participants (Caravale, Moscati 2021, in part. 91-94). The high number of sessions at the conference that celebrated the CAA's 50th anniversary in Amsterdam in April 2023 is valuable evidence of its popularity today.

CAA too is actively pursuing the open and free access to all its proceedings volumes. Digital versions up to 2011 can be accessed via the online Proceedings portal (https://proceedings.caaconference.org/), and from 2012 to 2017 at the CAA Proceedings Bibliography web page (https://caa-international.org/publications/proceedings/bibliography/).

The CAA data was, for the most part, provided by the A&C editors, but was also supplemented by querying OpenAlex (Priem, Piwowar, Orr 2022). For present purposes the most relevant features of this dataset are the title, abstract and year of publication. After some light data pre-processing (such as removal of duplicates and nulls), and once again limiting the data to the period 2011-2020, the dataset consists of 514 records. Note that the records pertaining to the period 2011-2017 correspond to CAA conference proceedings, whereas those from 2018 until 2020 correspond to articles

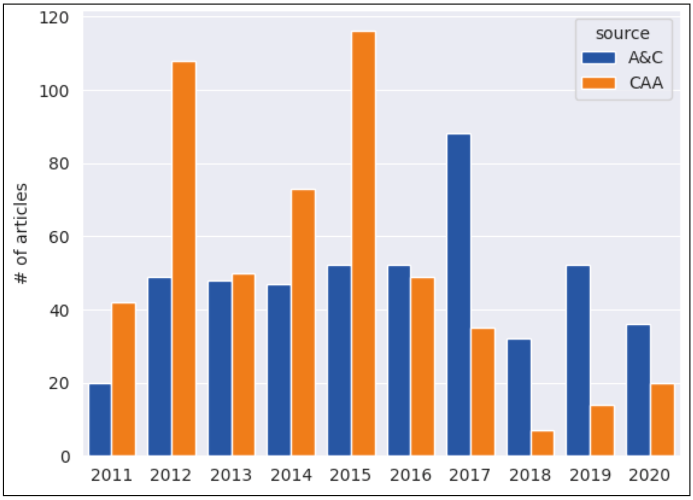

Fig. 1 – Bar chart showing the number of articles per year distinguished by source.

published in the newly launched «Journal of Computer Applications in Archaeology» (JCAA).

In Fig. 1, we see the number of articles per year distinguished by source. Numbers are relatively constant for A&C (with the exception of a significant increase in 2017, which is explained by the publication of two issues, the second one dedicated to the proceedings of the KAINUA 2017 International Conference on Knowledge, Analysis and Innovative Methods for the Study and the Dissemination of Ancient Urban Areas: Garagnani, Gaucci 2017). On the other hand, we see a bigger variation for CAA. In this case, the increase in 2012 and 2015 can be explained by the 40th anniversary of the conference (Earl *et al*. 2013) and the highly attended edition held in Siena (Campana, Scopigno, Carpentiero 2016), respectively. The drop in the last three years is due to the fact that the publication of the proceedings is paused since the 2018th edition, which is why the data for that period are extracted from the JCAA.

3. Methods

Our analysis of the A&C publications relies significantly on a prior process of information retrieval carried out by leveraging on multiple AI-based techniques. In this section, we describe the main methods employed and the results obtained, from a technical point of view.

The main tasks we have carried out, which will be described in detail shortly, are:

Geophysical methodologies compared to the late antique villa of Aiano-Torraccia di Chiusi (Siena): some note on efficacy and limits

During the years 2006-2007, three teams of scientists (archaeologists with geophysicists) detected the archaeological surface of the Late Antique villa at Aiano-Torraccia di Chiusi (Siena, Tuscany) using GPR (Ground Penetrating Radar), Resistivity and Magnetometry. Their aim was to identify archaeological remains and consequently spend less time and money on digging. At the conclusion of the fieldwork and data treatment, they used a CAD program to overlap geophysical and archaeological layers and check geophysical results on archaeological remains. Despite surveys in many other archaeological sites, they obtained few results: surveys located anomalies in less than 1/4 of the archaeological remains excavated in 2008 and 2009. In this paper the authors attempt to analyze (and try to find better solutions for the future) errors in the geophysical surveys caused by incorrect calibration of the database, low accuracy of grid intersections and excessively long grid lines, in relationship to site conditions and the kinds of archaeological remains. These technical problems in fact certainly create a less than optimal operational synergy between archaeologists and geologists during the post-processing of the data: an analysis of these problems may help to improve future projects of this type.

NER-time period Geotagging Technologies
Topic: Remote sensing
ACM classes: Computer graphics, Modeling and simulation, Spatial-temporal systems

Tab. 1 – Example of a title and abstract from the A&C collection with the results of applying all techniques to them, including NER, Geotagging, Technology identification, Topic modelling and Supervised classification.

1. A supervised classification into subfields of computer science, based on data labelled with the Association for Computing Machinery (ACM) taxonomy.
2. Topic modelling, in order to discover emergent topics from the title and abstracts of the publications.
3. Technology identification, to match articles with the technologies mentioned in them.
4. Named Entity Recognition (NER) to identify specific entities that are relevant from an archaeological point of view.
5. Geotagging, to link articles with the geographical locations they are about.

In Tab. 1 we illustrate all of these tasks with an example of an article's title and abstract with all the corresponding extracted information.

3.1 *ACM classification*

For this task, our aim is to classify the A&C publications according to their topic within the field of Computer Science. To this end, we make use of data from the Association for Computing Machinery (ACM) taxonomy in order to train a text classification model. The ACM taxonomy (https://dl.acm.org/ccs) is a hierarchical ontology of subfields of computer science, including up to six nested levels of categories per document, and a total number of 1961 categories of all levels. There are two main taxonomies proposed by the ACM: one dating back to 1998 and a second one proposed in 2012. Our data is labelled with the latest one.

The ACM dataset employed contains 258.103 publications (with their associated title and abstract). As one would expect, the vast majority of categories are irrelevant for our field of interest, archaeology, so we decided to select a limited number of categories that were applicable. This selection was based mostly following the advice of the A&C editors. We selected 17 categories belonging to different levels of the hierarchy and treated all of them on a par, turning the task into a (non-hierarchical) multi-label classification problem.

The selected categories are: 'Computer graphics', 'Computer vision', 'Data mining', 'Decision support systems', 'Digital libraries and archives', 'Document management and text processing', 'Education', 'History of computing', 'Human-centered computing', 'Information retrieval', 'Machine learning', 'Modeling and simulation', 'Multimedia information systems', 'Natural language processing', 'Probability and statistics', 'Spatial-temporal systems', 'World Wide Web'.

The original ACM dataset was mainly composed by computer science and engineering publications. For this reason, we were concerned that a system trained with this data would not be able to generalise well in a domain as specific as archaeology. In order to check and potentially mitigate this bias, we trained models on three different training sets:

1) A general random sample of the original dataset.
2) A sample of publications which belong to Social Sciences and Humanities (SSH) domains. We did this by filtering the data according to whether they belonged to SSH related subcategories (e.g. 'anthropology', 'ethnography', 'economics', 'sociology', 'arts and humanities', 'fine arts').
3) A mix of the general random sample and the SSH publications.

Moreover, we split a test set for the general domain, one for the SSH domain and (a much smaller) one for the archaeology domain, simply filtering by the ACM category 'archaeology' (note that we removed the archaeology and the SSH-test data from the domain-specific and the general-domain training data).

For classification, as suggested in Cohan *et al.* 2020 and Singh *et al.* 2022, we train a linear support vector machine (SVM) on embeddings of concatenation of title and abstract, training a classifier for each category (Tab. 2).

Results show that in-domain training performs better both for general and SSH test data. In the case of publications in the archaeology domain, the classifier trained only on SSH publications performs much better than other options. Given the high F1[1] of this configuration, we take the model trained on the SSH dataset for our analysis of A&C and CAA publications.

[1] The F1 metric is widely used for evaluating classification tasks. It is defined as the harmonic mean of the precision and the recall metrics (where precision is the number of true positive results divided by the number of all positive results and recall is the number of true positive results divided by the number of all samples that should have been identified as positive). In other words, the F1 tells us both how correct and how complete our results are.

Training data	**General (test)**	**SSH (test)**	**Arch. (test)**
General	**0.690**	0.618	0.668
Mixed	0.670	0.614	0.600
SSH	0.600	**0.652**	**0.889**

Tab. 2 – Comparison of the macro-avg F1 between training data and test by domain.

3.2 *Topic modelling*

As briefly explained in the Introduction, topic modelling is an unsupervised machine learning technique that aims at automatically identifying texts that have semantic similarity and which is used to reduce complexity of textual corpora. Topic modelling techniques have been widely used for the identification of scientific topics in literature (Griffiths, Steyvers 2004; Callaghan, Minx, Forster 2020; García *et al.* 2020). From a technical point of view, while different methods and algorithms have been proposed to detect the topics, the use of pre-trained language models (PLM) based on Transformers such as BERT (Bidirectional Encoder Representation from Transformers: Devlin *et al.* 2019) is becoming increasingly popular for topic modelling (Stanik, Pietz, Maalej 2021; Sangaraju *et al.* 2022). In particular, we apply SPECTER (Cohan *et al.* 2020) – following the implementation in Bovenzi *et al.* 2022 – a BERT pre-trained model fine-tuned on scientific corpora and which also relies on citations in order to generate highly useful vectorial representations of scientific texts that produce embeddings for all texts (containing title and abstract), and then we use K-Means, an unsupervised clustering technique on top of the encoded vectors.

To find the best number of topics, we ran the K-Means by varying the number of clusters and we eventually chose to extract 10 clusters (i.e. topics) by qualitatively choosing the best trade-off between the semantic 'richness' of the topics and the overall number of topics (in order not to have neither too large clusters nor too little ones). Each cluster is therefore a topic and close vectors are thematically-related documents. Moreover, a domain expert manually selected a topic label for each topic. In Tab. 3, we list the final topics we detected together with the top keywords that appeared with most frequency in their documents. The lists of keywords have been slightly revised to provide a more intuitive description of the contents of the topics. We have deleted a few keywords that were irrelevant and that appeared across multiple topics.

3.3 *Technology identification*

An important type of information we retrieve from the titles and abstracts of the articles are the technologies mentioned in them. This level of analysis provides a new perspective with respect to the ACM classification in that we

	Topic label	Top keywords
0	**Artificial Intelligence**	neural, software, ontology, analytical archaeology, adaptive, computational, dataset, archaeology artificial, humanity
1	**GIS and spatial analysis**	archaeological datum, gis, geographical, archaeological information, geographic, archaeological research, documentation, archaeological site, software
2	**Imagery analysis**	image, reflectance, artefact, infrared, sense, multispectral, drawing, recognition, photograph, painting
3	**Material culture**	pottery, artefact, ceramic, archaeological site, archaeological datum, bone, stratigraphic
4	**Modeling and simulation**	simulate, settlement, computational, prehistoric population, climatic, gatherer, human foraging, geographical
5	**Digital cultural heritage**	cultural heritage, culture, archive, museum, archaeological datum, archaeological research, historical, digital cultural, humanities
6	**Photogrammetry and 3D scanning**	photogrammetry, photogrammetric, reconstruction, architectural, 3d model, scan, architecture, scanner, archaeological excavation, monument
7	**Remote sensing**	lidar, archaeological site, scan, geophysical, aerial, lidar datum, sense, remote sensing, airborne, terrain
8	**Semantic technologies**	archaeological datum, semantic, dataset, archive, archaeological information, documentation, semantic web, catalogue, software, archaeological database
9	**Virtual reality**	virtual, museum, interactive, immersive, reconstruction, vr, cultural heritage, archaeological site, artefact, exhibition

Tab. 3 – Most frequent keywords found in the documents belonging to each topic.

can go beyond computer science and extract insights about technology more generally. Moreover, it distinguishes itself both from the ACM classification and from the topic modelling in that the granularity achieved is a lot finer.

To perform this task, we make use of a controlled vocabulary (VOC). In particular, we use a VOC of technologies relevant for the field of Heritage Science (Duran-Silva *et al.* 2021), which was built by SIRIS Academic and the Istituto Regionale per la Programmazione Economica della Toscana, and which describes a set of key enabling technologies for culture and cultural heritage, many of which are in particular relevant for the field of computational archaeology (the list of key enabling technologies was mostly based on the proposal put forward in Borrione *et al.* 2019).

The list contains 905 keywords referring to technologies (such as 'machine learning', 'geographic information system', 'optical laser', '3D model', etc.), which are in turn classified in types (e.g. 'Lidar' is classified as belonging to the class '3D SCAN, PHOTOGRAMMETRY 3D/4D').

For each entry of the controlled vocabulary, we query the Wikipedia API (https://github.com/goldsmith/Wikipedia) and look for its corresponding suggested articles, the summaries of which we then vectorize (with SPECTER-2; Singh *et al.* 2022) to obtain their embeddings. These embeddings are compared with the embedding of the Wikipedia entry for 'Computational Archaeology' and the one with the highest cosine similarity with respect to it is chosen as the correct one, i.e. the one capturing the definition of that technology, if it is high enough in the Wikipedia results list[2]. This method allows us to disambiguate between possible meanings of the technologies' names.

To give an example, when we search for 'drone' in Wikipedia, we get the following candidate results:

Drone (bee) – a male honey bee.
Unmanned aerial vehicle – a generic drone.
Delivery drone – a drone used to transport packages.
Drone warfare – a form of aerial warfare using unmanned combat aerial vehicles.
Unmanned combat aerial vehicle – a combat drone.
Drone (sound) – a type of sound used in some forms of music.
Drone music – a music genre.
Drone art – a form of art produced with drones.
Droners – a French animated series.

By looking at the semantic similarity between the embeddings of their summaries and the embedding of 'Computational Archaeology' and taking also into account the position of the entries in the list of results, we obtain, correctly, that the relevant entry is B.

Once we have an embedding for each technology listed in our VOC, we proceed to match the technologies with the titles and abstracts of the publications. This involves a two-step process. First, we look for matches amongst the noun phrases contained in the titles and abstracts (these matches are fuzzy[3], in the sense that they allow for degrees: the higher they are, the less spelling differences between the terms). Second, we compute the cosine similarity between the SPECTER-2 embeddings of the titles and abstracts and the technologies' embeddings (obtained in the previous step). Finally, we use a manually set threshold depending both on the degree of fuzzy match and the embeddings' similarity in order to decide whether each noun phrase matches any of the technologies. Thus, whether an article is about a certain technology or other is decided both by looking at the degree of match of strings of characters, but also at the degree of semantic similarity between the meaning of the titles and abstracts and the descriptions of the technologies. This combined measure provides the right balance between looking only at purely surface morphological features (often too strict a criterion) and looking only into the semantic representation of concepts (often too imprecise a criterion).

[2] The reason why we take into account not only similarity with the meaning of 'Computational Archaeology', but also the position in which an entry appears in the list of results is that Wikipedia provides results sorted by relevance, which is often a useful measure for us, since completely irrelevant results are very unlikely to be the ones we are looking for.

[3] To do fuzzy matching, we use the Fuzzywuzzy library, which can be found here: https://github.com/seatgeek/fuzzywuzzy.

Entity	*F1-score*
Artefact	0.80
Time Period	0.81
Context	0.64
Material	0.68
Location	0.73
Specie	0.69
Overall	0.80

Tab. 4 – The F1-score obtained for each category of named entities.

3.4 *Archaeological NER*

Named Entity Recognition (NER) is the task of identifying important entities mentioned in an unstructured text. This type of information extraction allows the access to a finer level of granularity than techniques like supervised classification or topic modelling. Generic NER tasks focus on extracting expressions such as person names, locations, organisations, time expressions or quantities. However, for this study we trained a specialised NER model, which extracts only archaeologically relevant entities. To this end, we built on previous work in which an archaeological NER was trained on excavation reports in Dutch (Brandsen *et al.* 2020). Our strategy was to first automatically translate the Dutch training data into English, with the DeepL API (https://www.deepl.com/), and then retrain a NER model based on it.

The evaluation metrics obtained training on 80% of the datasets and evaluating on the other 20% are summarised in Tab. 4. Note that the results in English are more competitive than the results for Dutch text reported by the original paper (Brandsen *et al.* 2020).

For the purposes of our analysis, the type of identified entity that proved most relevant was Time Period, so in the Results and Discussion sections, we focus solely on it.

3.5 *Geotagging*

By geotagging a text we can get, in an automatic way, the geographical scope of a document (Andogah, Bouma, Nerbonne 2012), which can be especially interesting in a field like archaeology. More precisely, geotagging consists of 1) the identification of geographic entities in a text, and 2) toponym resolution, namely, linking them with their corresponding spatial location. The first part is a special case of NER. In order to perform this task, we make use of two pre-trained and openly available models: GeoText (https://github.com/elyase/geotext) and Geograpy3 (https://github.com/somnathrakshit/geograpy3) (we join their outputs to obtain more comprehensive results).

In order to perform toponym resolution we match the identified locations against the geographic database Geonames (via the Local-geocode library) (https://github.com/mar-muel/local-geocode), thereby obtaining their geographic coordinates. Note that, even though GeoText and Geograpy occasionally identify entities which are not locations, the process of toponym resolution filters out most of the previously introduced errors.

4. Results

4.1 *ACM classification*

The first set of results concerns the predictions of our ACM classifier. In Fig. 2 we can see the distribution of predicted categories on the A&C publications. The model predicts a high number of publications to be about Human-centered computing. This is explained from the fact that this is a level 0 category within the ACM taxonomy which encompasses many relevant sub-categories for us (interaction design, virtual reality, social media,

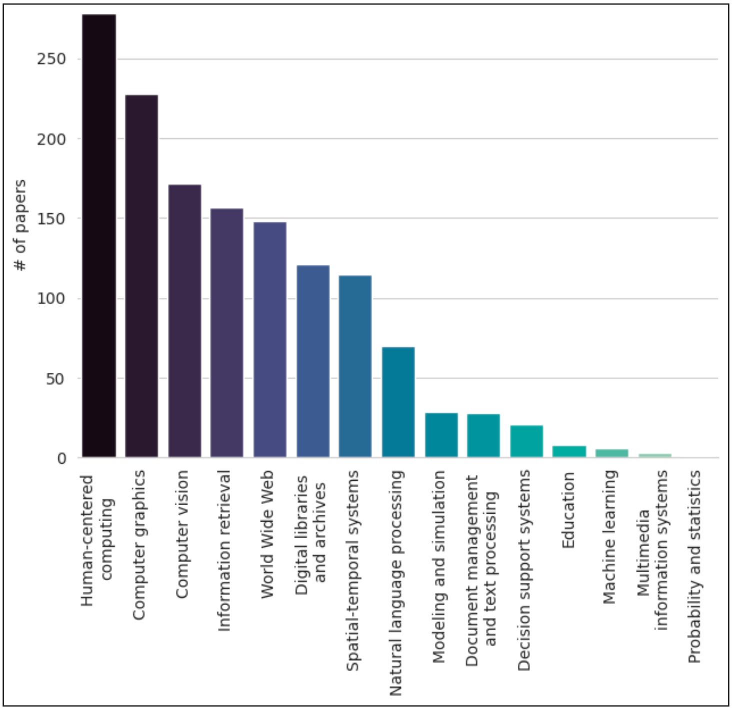

Fig. 2 – ACM classification: distribution of predicted categories on the A&C publications.

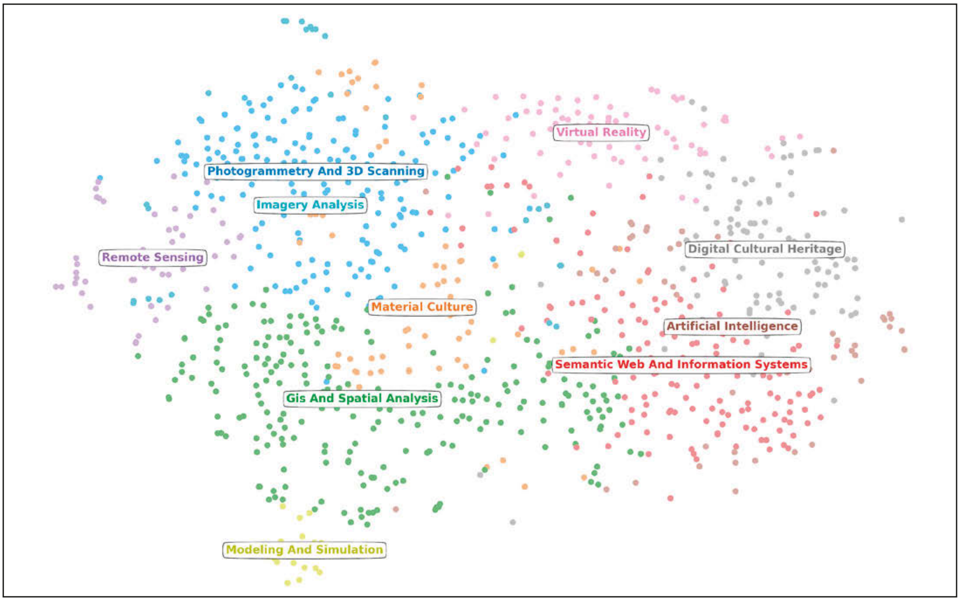

Fig. 3 – Emerging topics: results of the topic modelling as applied to the A&C and CAA data.

collaborative computing, visualisation, etc.). Another notable category is Computer vision. This category must be understood in a broad way, since it contains sub-categories such as Image representation, Image and video acquisition or 3D imaging, thus under the ACM definition it is highly instantiated in our dataset.

4.2 *Emerging topics*

In Fig. 3, we have mapped the results of the topic modelling as applied to the A&C and CAA data. It can be seen as a mapping of the field of digital archaeology from 2011 to 2020. In the plot, each dot represents a publication, the colours represent each of the 10 identified topics and the distance between dots represents semantic similarity between the titles and abstracts of the different publications. Consequently, the proximity between topics must also be interpreted as capturing their similarity.

In Fig. 4, we can see more clearly the amount of papers that fall under each topic and, moreover, we can see it separately for each publication. Unsurprisingly, GIS and Spatial Analysis is the most populated topic for both sources. Moreover, even though there are some disparities, A&C seems to be well represented in all identified topics, with the exception of Imagery analysis and Modeling and Simulation, where CAA has a significantly higher production.

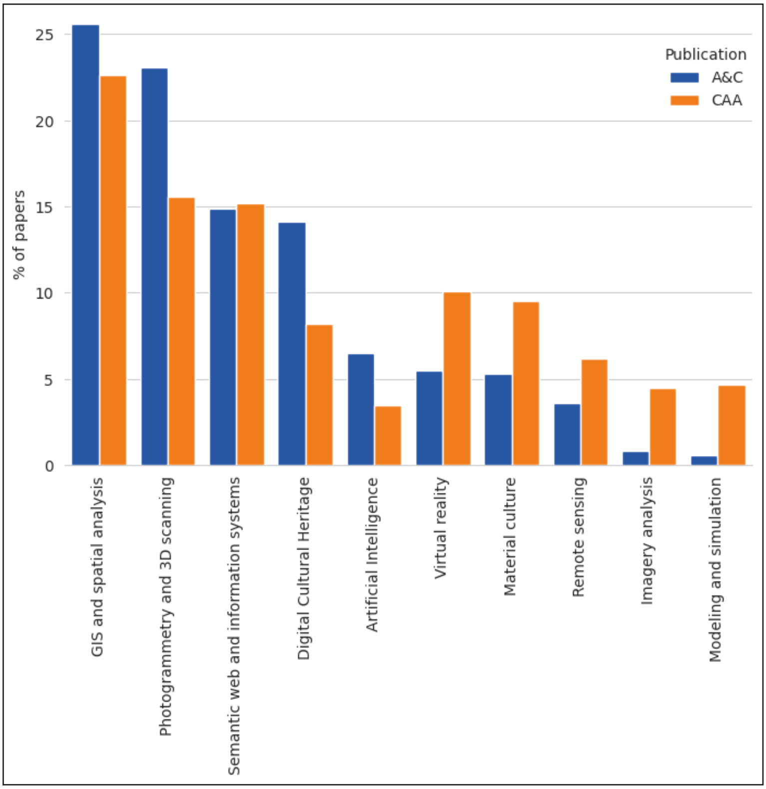

Fig. 4 – Amount of papers that fall under each topic, shown separately for each publication.

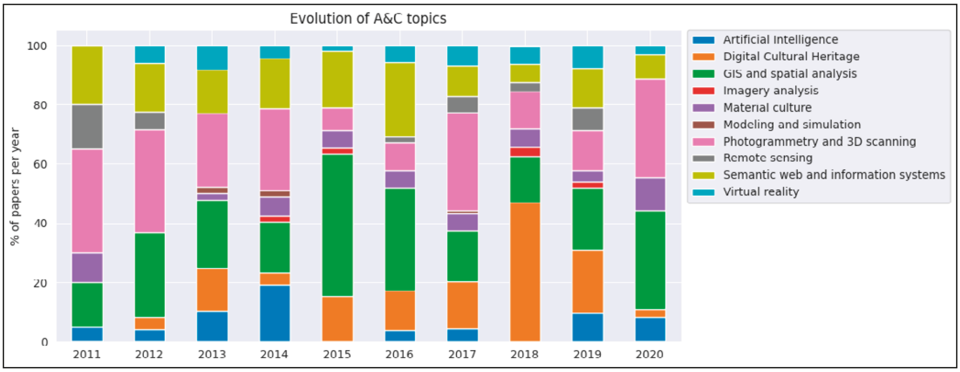

Fig. 5 – Chronological evolution of topics in A&C publications, represented as percentages of the number of articles per year.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Artificial Intelligence	1	2	5	9	0	2	4	0	5	3
GIS and spatial analysis	3	14	11	8	25	18	15	5	11	12
Imagery analysis	0	0	0	1	1	0	0	1	1	0
Material culture	2	0	1	3	3	3	5	2	2	4
Modeling and simulation	0	0	1	1	0	0	1	0	0	0
Digital cultural heritage	0	2	7	2	8	7	14	15	11	1
Photogrammetry and 3D scanning	7	17	12	13	4	5	29	4	7	12
Remote sensing	3	3	0	0	0	1	5	1	4	0
Semantic web and information systems	4	8	7	8	10	13	9	2	7	3
Virtual reality	0	3	4	2	1	3	6	2	4	1

Tab. 5 – Time evolution of the absolute numbers of A&C publications belonging to each topic.

Finally, in Fig. 5 the time evolution of topics in A&C publications is represented (as percentages of the number of articles per year), while in Tab. 5 we can see the same data in absolute numbers represented in tabular form.

4.3 *Identification of technologies*

In Fig. 6, we answer two questions: what technologies are most frequently mentioned in A&C articles and how do their relative frequencies compare with their frequencies in CAA. In particular, we see represented the Top 20 most cited technologies in A&C. Finally, we can check the evolution in time of the technology mentions in A&C. In the following barplot (Fig. 7), we see the evolution of the 5 most mentioned technologies.

4.4 *Time periods prevalence*

By using NER, we were able to identify the time periods mentioned in A&C publications, bearing in mind that we have only taken into account terms that appear at least twice in our corpus. Moreover, we have grouped specific time periods into the 6 main groups that are represented in the figures, for ease of interpretation. For instance, 'Roman' was classified as CLASSICAL ANTIQUITY, 'Bronze Age' as PROTOHISTORY and 'Romanesque' as MIDDLE AGES (Fig. 8). If we do benchmarking with these results, we observe that CAA contains considerably less mentions of time periods across the whole classification (Fig. 9).

4.5 *Geographical scope*

Finally, Fig. 10 answers the question of what is the geographical scope of the A&C and the CAA publications. In this map, we project each location mentioned in A&C (red) and CAA (blue). We notice, as expected, that A&C contains a high concentration of locations in Italy. To see it more clearly,

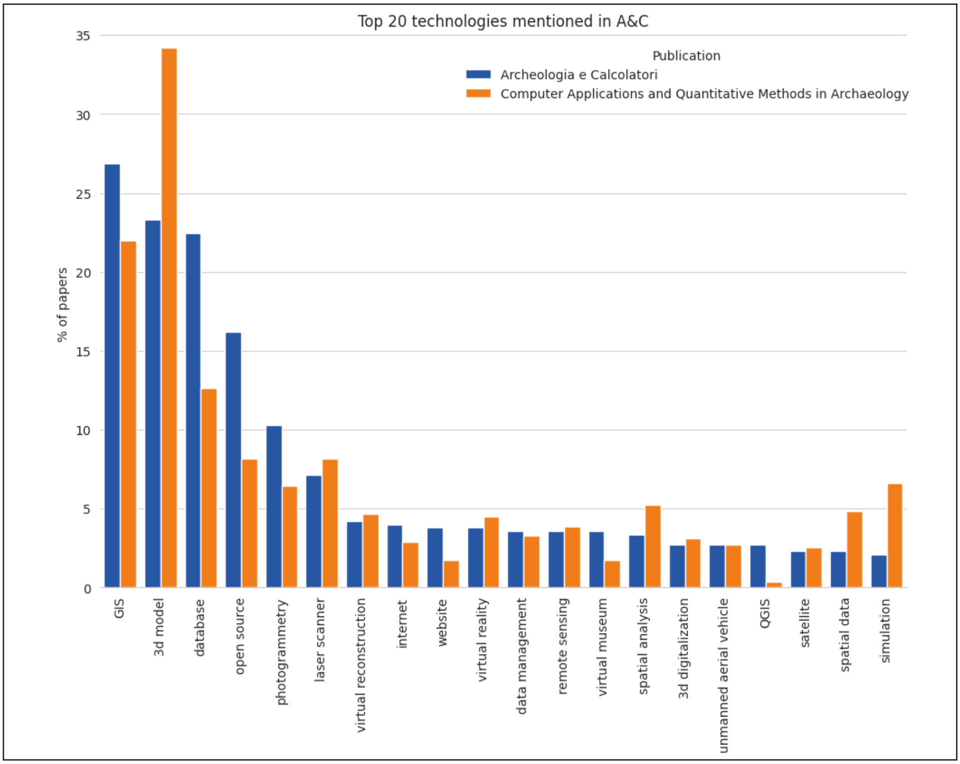

Fig. 6 – Barplot showing the Top 20 most cited technologies in A&C and their relative frequencies compared with those cited in CAA.

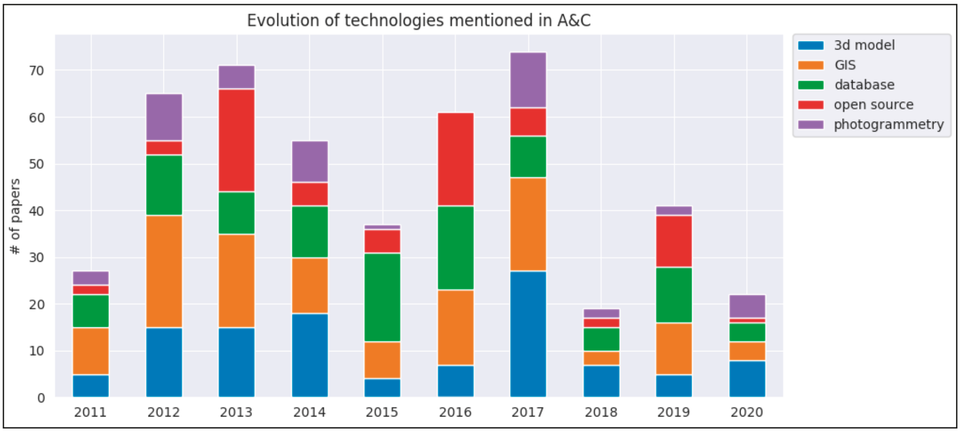

Fig. 7 – Barplot showing the evolution of the 5 most mentioned technologies in A&C.

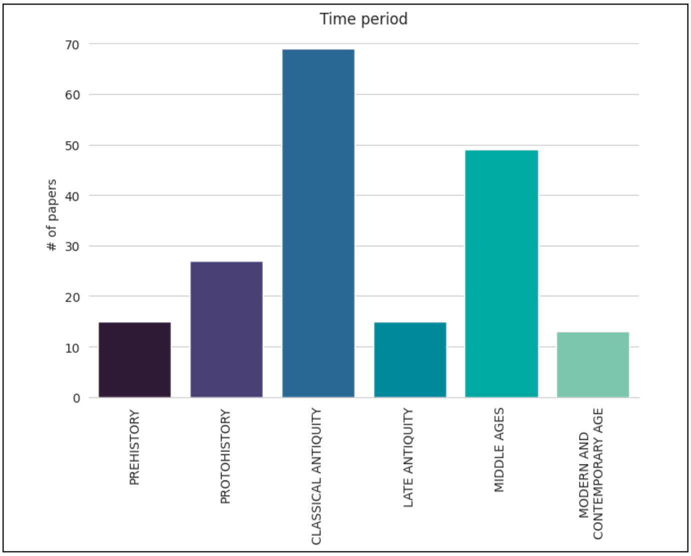

Fig. 8 – Numerical overview of the time periods mentioned in A&C publications.

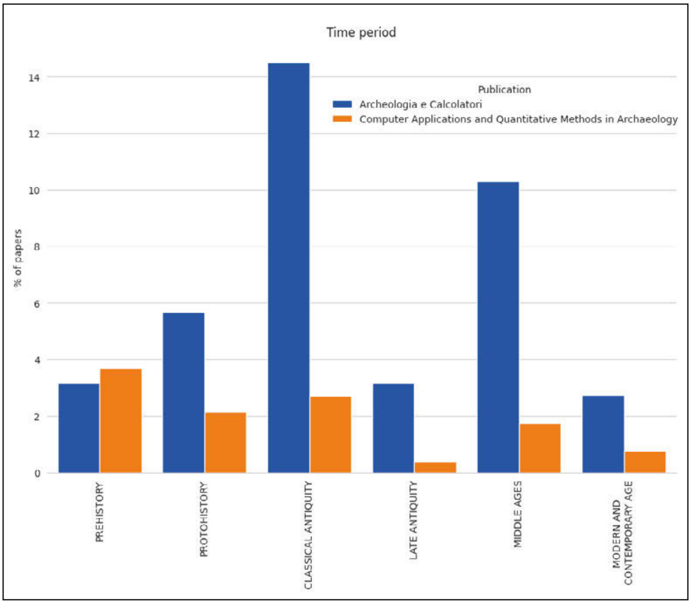

Fig. 9 – Amount of papers mentioning time periods in A&C and CAA data.

Fig. 10 – Geographical scope of the A&C and the CAA publications. On the map, each location mentioned in A&C (in red) and CAA (in blue) is projected.

we zoom in on Italy (Fig. 11). There are a few CAA locations, but the vast majority correspond to A&C publications.

5. Discussion

The results illustrated in the previous section are a further step towards the new classification of the main cross-cutting themes featuring computer applications in archaeology in the Third Millennium that we have been dealing with since the publication of the A&C 30th issue. Indeed, the recent trend of digital archaeology to merge into the broader fields of Digital Cultural Heritage and Heritage Science implies a change of course as far as the description, distribution and classification of the application fields of computer science to archaeology are concerned. They are strongly informed by the rapid and compact progress of STEM disciplines on the one hand, and the Creative Industry on the other, resulting in a broad spectrum of technological innovations, which seem to escape any attempt at systematic classification.

The previous content analysis of the articles published in the journal and its Supplements over the last two decades was conducted using geographical text mapping strategies, multidimensional analysis techniques and the Social Network Analysis, to explore the relationship between archaeological themes and information technologies. The analysis illustrated in this paper focuses mainly on technological aspects and its first outcome allows us to check the

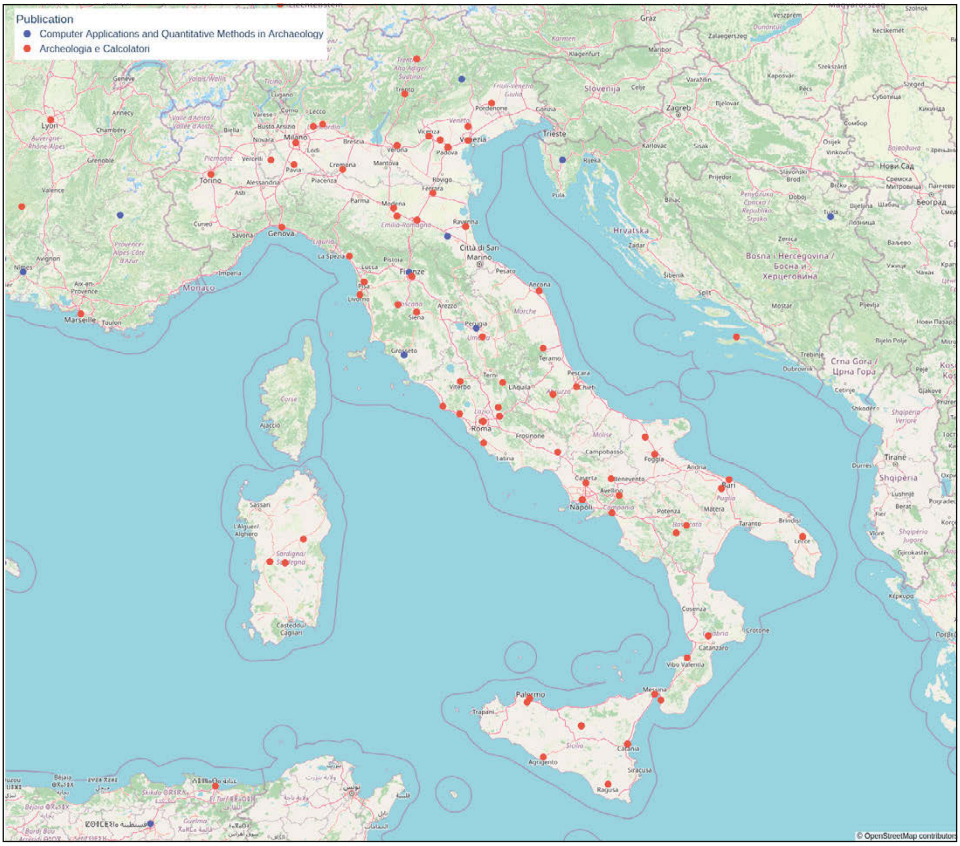

Fig. 11 – The same results as in Fig. 10, zoomed in on Italy.

consistency between the entries of the journal's list of 10 ICT topics[4] and what can be achieved by the application of various AI-based techniques, with both descriptive and predictive purposes.

Before discussing the results, a premise is necessary. As far as the comparison between A&C and CAA datasets is concerned, the results should take into account the publishing venue and its scope. A scholarly journal generally publishes the papers like they are spontaneously submitted by the authors, and thus, by its very nature, it tracks ongoing methodological trends and their evolution. In contrast, conference proceedings are often grouped according

[4] Computer graphics IP CAD, Data encoding and metadata, Database, GIS and cartography, History of applications and research projects, Multimedia and web tools, Remote Sensing, Simulation AI, Statistics, Virtual Reality and 3D modelling.

to the topics suggested by the organizers and, in recent years, by the 'call for sessions' process. In our case, the gap can be bridged to some extent thanks to the publication of conference proceedings and thematic issues within the journal and its Supplements, which provide grounds for comparison.

The first set of results, i.e. the supervised classification into subfields of computer science based on data labelled with the ACM taxonomy (Fig. 2), shows that the 15 selected categories have strong similarities with the A&C 10 ICT topics. Indeed, 'human-centered computing' corresponds to our history of applications and research projects, 'information retrieval' bears a strong relationship with database management systems, 'spatio-temporal systems' correspond to GIS, 'computer graphics' and 'computer vision' find a strong correlation with CAD, BIM and Virtual Reality applications. Not surprisingly, applications related to AI (modelling and simulation, decision support systems, machine learning techniques) continue to be statistically less frequent in archaeology, while it is worth analyzing the expected future decline of methods labelled 'probability and statistics'. These methods, which underlie the rise of quantitative archaeology in the 1960s, are currently part of the research practice, and thus their application is often taken for granted. In the last issues of the journal, however, the presence of an increasing number of articles based on statistical techniques and their heuristic potential (more than 15 in 5 years) – maybe also due to the widespread use of the powerful and versatile R open source software – seems to contradict this result.

The outcomes of topic modelling are self-evident, but additional insights into the 10 clusters (i.e. topics) and the relative top keywords may be useful to suggest how to expand the classification of the journal's articles in the future. Let us take the topic 'Imagery analysis' as an example. Beyond the technical aspects, the list of keywords clearly identifies specific areas of advanced knowledge management, where interdisciplinary applications are closely intertwined with the development of AI tools. The scientific implications are manifold and impressive, ranging from the analysis and interpretation of remote sensing imagery to the automatic recognition of archaeological potsherds.

Data on the evolution of the 5 most frequently mentioned technologies in A&C (Fig. 8) can be read as indicators of two well-defined issues in today's digital archaeology: the use of more 'traditional' and well-established methodologies, such as GIS and databases – which over time have maintained their role as key tools in the management of archaeological data – alongside more recent and progressively emerging techniques, such as digital photogrammetry and three-dimensional modelling. Their frequent occurrence in the recent issues of the journal, partially interrelated with the publication of conference proceedings specifically dedicated to these topics, underlines their success as tools for documenting the past, at a time when visual data have acquired a key role in both the research and the dissemination of archaeological results.

For instance, ISPC, which coordinates the Italian node of the European research infrastructure on Heritage Science E-RIHS.it, has many research Labs dedicated to these topics (https://www.ispc.cnr.it/en/ricerca/gruppi_e_labs/).

The case of the 'open source' entry is quite different. With respect to software development, this undoubtedly indicates its cross-cutting role in interacting with the other four technologies. Its presence can be associated with the journal's close cooperation with the ArcheoFOSS community, which since 2006 has been promoting open tools and technologies in the academic, professional and institutional Cultural Heritage domain, choosing the journal as a publishing venue for its workshops proceedings. However this result could also be linked to the dissemination of the wider open access movement, whose principles have been embraced by the journal since 2005 and today constitute the very lifeblood of the 'Open Data, Open Knowledge, Open Science' ISPC research Lab (https://www.ispc.cnr.it/en/2020/05/14/gruppo-open-data/).

Lastly, the results on geographical and chronological scope should deserve further investigation. The geographical distribution of the sites mentioned in A&C in the last five years (2014-2018) was investigated in 2019 thanks to the use of the Recogito tool as part of the Pelagios Network (Cantone, Caravale 2019). It can now be compared to data resulting from the automatic mapping (Figs. 10-11) to cover a large number of published issues. The territorial scope resulting from both analyses is wide, with a distribution throughout the Mediterranean area and beyond. A dominant role is no doubt played by the sites of our Peninsula, but a distinctive feature is definitely the great involvement of European Mediterranean countries, an achievement that vindicates the journal's pioneering choice to adopt the multilingualism approach. This finding emphasises the international nature of A&C, which focuses on wide-ranging initiatives in digital archaeology, in line with the policy traced in the opening editorial of the first issue, which stressed the need to exploit ongoing projects both in Italy and abroad (Cristofani, Francovich 1990).

Benchmarking with the results for the time periods mentioned in both A&C and CAA is a complex task, because the classification, as pointed out above, is currently too broad and will need to be further articulated. As for A&C, the prevalence of Classical Antiquity and Middle Ages fully matches the aims of the journal, which was launched in 1990 to collect and illustrate research projects conducted predominantly in the field of classical and post-classical archaeology. In any case, the chronological span is quite comprehensive, from prehistory to the modern age, indicating how widespread is the use of digital technologies in all fields dedicated to the study of Antiquity.

The reason that CAA publications contain only a few mentions of time periods across the whole classification is mainly due to the different publication venue. A&C, in fact, dedicates extensive articles (around 6000 words) to specific archaeological sites and monuments, comprehensively described in their geographical and chronological context, and, by its mission, only accepts papers giving equal emphasis to the archaeological and the technical aspects, in order to highlight the contribution of information technology to the development of archaeological research methods.

6. Conclusion

Although the results presented here can only be taken as a first approximation to be expanded in the future including the unpublished CAA conference Books of Abstracts and the last 4 issues of A&C, until reaching our ultimate goal, i.e. the analysis of the full texts of the A&C articles, they provide interesting insights into the latest advances in the field of digital archaeology, as discussed in the previous section.

This experiment shows the importance of combining different methods to better represent and analyse scientific literature, its contribution and evolution. The increasing availability of open metadata and open research information (eg. OpenAire or OpenAlex) offers a great opportunity to build more customised and multidimensional analyses beyond applying a predefined classification scheme. This semantic-based approach, including bottom-up information extraction techniques (such as Topic Modelling or Named-Entity Recognition) is particularly relevant for mapping and understanding the contribution of humanities and social sciences, such as archaeology (and especially so for interdisciplinary and rapidly changing fields, such as digital archaeology), where the use of traditional classifications (e.g. by discipline or journal) has demonstrated to be limited.

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REFERENCES

Andogah G., Bouma G., Nerbonne J. 2012, *Every document has a geographical scope*, «Data & Knowledge Engineering», 81-82, 1-20 (https://doi.org/10.1016/j.datak.2012.07.002).

Borrione P., Carrozzino M., d'Orsi P., Iommi S., Lunghi M., Siotto E. 2019, *IRPET. Report della piattaforma "Tecnologie, Beni Culturali e Cultura". Le roadmap dello sviluppo e dell'innovazione (RIS3)*, Firenze, Regione Toscana (http://www.irpet.it/archives/53165).

Bovenzi N., Duran-Silva N., Massucci F.A., Multari F., Pujol-Llatse J. 2022, *Mapping STI ecosystems via open data: Overcoming the limitations of conflicting taxonomies. A case study for climate change research in Denmark*, in *Linking Theory and Practice of Digital Libraries, 26th International Conference on Theory and Practice of Digital Libraries, TPDL (Padua 2022), Proceedings*, Springer, Cham, 495-499 (https://doi.org/10.1007/978-3-031-16802-4).

Brandsen A., Verberne S., Wansleeben M., Lambers K. 2020, *Creating a dataset for Named Entity Recognition in the archaeology domain*, in *Proceedings of the 12th Language Resources and Evaluation Conference*, Marseille, European Language Resources Association, 4573-4577.

Campana S., Scopigno R., Carpentiero G. (eds.) 2016, *CAA2015. Keep The Revolution Going. Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*, Oxford, Archaeopress.

Cantone F., Caravale A. 2019, *Archeologia e Calcolatori. Classificazione geografica e tematica per la condivisione della conoscenza*, in Moscati 2019, 93-107 (https://doi.org/10.19282/ac.30.2019.07).

Callaghan M.W., Minx J.C., Forster P.M. 2020, *A topography of climate change research*, «Nature Climate Change», 10, 118-123.

Caravale A., Miliani C., Moscati P., Sfameni C. 2021, *La sfida delle competenze per il Patrimonio Culturale: complementarità, integrazione, interazione*, in A. Filippetti (ed.), *Le Scienze Umane, Sociali e del Patrimonio Culturale nell'era delle grandi transizioni*, Roma, CNR Edizioni, 65-86.

Cohan A., Feldman S., Beltagy I., Downey D., Weld D. 2020, *SPECTER: Document-level representation learning using citation-informed transformers*, in *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, Association for Computational Linguistics, 2270-2282 (https://doi.org/10.18653/v1/2020.acl-main.207).

Devlin J., Chang M., Lee K., Toutanova K. 2019, *BERT: Pre-training of deep bidirectional transformers for language understanding*, in *Proceedings of the 17th Annual Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies (NAACL-HLT 2019, Minneapolis 2019)*, Association for Computational Linguistics, 1, 4171-4186 (https://doi.org/10.18653/v1/N19-1423).

Duran-Silva N., Parra-Rojas C., Rondelli B., Giocoli L., Plazas A., Grimau B. 2021, *A controlled vocabulary for research and innovation in the field of Cultural Heritage & Heritage Sciences [Data set]*, Zenodo (https://doi.org/10.5281/zenodo.8159015).

Earl G., Sly T., Chrysanthi A., Murrieta-Flores P., Papadopoulos C., Romanowska I., Wheatley D. (eds.) 2013, *Archaeology in the Digital Era: Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (Southampton 2012)*, Amsterdam, Amsterdam University Press (https://doi.org/10.2307/j.ctt6wp7kg).

Fuster E., Massucci F., Matusiak M. 2020, *Identifying specialisation domains beyond taxonomies: Mapping scientific and technological domains of specialisation via semantic analyses*, in R. Capello, A. Kleibrink, M. Matusiak (eds.), *Quantitative Methods for Place-Based Innovation Policy*, Cheltenham, Edward Elgar Publishing, 195-234.

Garagnani S., Gaucci A. (eds.) 2017, *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 2017), «Archeologia e Calcolatori», 28, 2 (https://doi.org/10.19282/AC.28.2.2017).

García D., Massucci F.A., Mosca A., Ràfols I., Rodríguez A., Vassena R. 2020, *Mapping research in assisted reproduction worldwide*, «Reproductive biomedicine online», 40, 71-81.

Griffiths T., Steyvers M. 2004, *Finding Scientific Topics. Proceedings of the National Academy of Sciences of the United States of America*, 101, Suppl. 1, 5228-5235 (https://doi.org/10.1073/pnas.0307752101).

Harping P. 2013, *Introduction to Controlled Vocabularies: Terminology for Art, Architecture, and Other Cultural Works*, Los Angeles, Getty Publications.

Levy P. 1994, *L'intelligence collective. Pour une anthropologie du cyberespace*, Paris, La Découverte.

Moscati P. 1999, *"Archeologia e Calcolatori": dieci anni di contributi all'informatica archeologica*, «Archeologia e Calcolatori», 10, 343-352 (http://www.archcalc.cnr.it/indice/PDF10/10_23_Moscati.pdf).

Moscati P. 2019 (ed.), *30 anni di Archeologia e Calcolatori. Tra memoria e progettualità*, «Archeologia e Calcolatori», 30, 9-138 (http://www.archcalc.cnr.it/journal/idyear.php?IDyear=2019-01-01).

Moscati P. 2021, *Digital archaeology: From interdisciplinarity to the 'fusion' of core competences. Towards the consolidation of new research areas*, «Magazén», 2, 2, 253-274 (https://doi.org/10.30687/mag/2724-3923/2021/04/004).

Priem J., Piwowar H., Orr R. 2022, *OpenAlex: A fully-open index of scholarly works, authors, venues, institutions, and concepts*, arXiv:2205.01833v2.

Sangaraju V.R., Bolla B.K., Nayak D.K., J. Kh 2022, *Topic modelling on consumer financial protection bureau data: An approach using BERT based embeddings*, in *2022 IEEE 7th International Conference for Convergence in Technology-I2CT (Mumbai 2022)*, IEEE, 1-6 (https://doi.org/10.1109/I2CT54291.2022.9824873).

Singh A., D'Arcy M., Cohan A., Downey D., Feldman S. 2022, *SciRepEval: A multi-format benchmark for scientific document representations*, arXiv:2211.13308v2.

Stanik C., Pietz T., Maalej W. 2021, *Unsupervised topic discovery in user comments*, in *2021 IEEE 29th International Requirements Engineering Conference (RE)*, IEEE, 150-161.

ABSTRACT

The Authors propose a knowledge map to analyse and access scientific contents related to Digital Archeology by leveraging various Machine Learning (ML) techniques. The case study concerns the articles published in our international journal «Archeologia e Calcolatori» in the decade from 2011 to 2020 and, as a benchmark, the publications in the 'Computer Applications and Quantitative Methods in Archaeology' (CAA) conference proceedings and journal. The titles and abstracts of the publications featured in these two data sets were analysed using a supervised classification approach into the subfields of computer science, based on the ACM's taxonomy, and by applying topic modelling techniques to discover emergent topics, Named Entity Recognition to identify specific archaeologically relevant entities, and geotagging techniques to link articles with the geographical locations they discuss. The results achieved, although preliminary, provide some methodological suggestions: i) the opportunity to build custom analyses by taking advantage of the increasing availability of open data and metadata; ii) the scope of the contribution of archaeology, and in particular of computational archaeology, to the Heritage Science interdisciplinary domain; the heuristic and predictive role of different ML techniques to gain a multi-faceted access to data analysis and interpretation.

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THE SPATIAL INTERACTIONS BETWEEN REMAINS IN LARGE DWELLING SPACES

1. Introduction

In studying human behaviours within prehistoric dwelling contexts and their surrounds, exploring the possible range of activities through the distribution analysis of artefacts and bioarchaeological remains, is a pivotal task in gaining any nuanced insight into social patterns of behaviour. Spaces affected by busy occupation and/or re-occupation over time, whose soils provide an intricate palimpsest of refuse deposition, are highly informative in reconstructing patterns of activities (Binford 1978), in some cases even more so than those characterised by the well-known 'Pompeii premise' (Schiffer 1985). Defining spaces and functions is a complex matter that requires the combination of different strands of analysis, from those suited to identifying the agents involved in the stochastic nature (Ferrari 2001) of deposit formation (Ascher 1968; Schiffer 1987; Leonardi 1992; Merrill, Read 2010) to those aimed at functionally characterising the artefacts and ecofacts found (Henrickson, McDonald 1983; Skibo 2012; Recchia *et al.* 2021) to finally mapping them.

Distribution (via a map) interpretation is the final step in the intertwined methodological approaches drawing their data from multi-analytical processes. Given that most human activities include the use of numerous tools and materials, we cannot confine our analysis to single categories of what is found where, rather it is critical to investigate and establish associations among them, albeit this step may have concealed pitfalls. In fact, contextualisation of the empirical data within the specific features of the context under scrutiny, essential to my own theoretical perspective (Hodder 1991; Shanks *et al.* 1995), meets the heuristic character of our decision-making process, something easily affected by the human brain's tendency to filter and simplify the complex palimpsest that makes up a typical archaeological record. As a result, when assessing a depositional set composed of a diverse and huge number of remains, a cognitive bias arising from our knowledge and experience (Kahneman, Tversky 1972; Blanco 2017) may beguile us into recognising the associations expected, whilst missing others hidden or beyond our personal experience.

Exploring such hidden connections in spatial data opens the way to figuring out further activities or actions, with the objects/ecofacts related to them. This article is aimed at providing a methodological approach to deal with this situation. Notably, by modelling all possible pairs of combinations between the categories of remains through the technique of the G-cross function, the proposed analysis will provide a method to address the question of how each category of remains interacts in the space with the other ones present (Baddeley *et al.* 2005, 2015; Gelb 2022). Specifically, this analysis verifies whether a set of points is spatially associated with any other, at multiple distances. Resulting models serve as null-model-based hypotheses, which can be successively tested by contextualising the archaeological data within the sociocultural and technological settings under scrutiny (Hodder 1991). For historical studies this continues to be the primary process to distinguish between merely correlating events and the ones with a causal relationship.

The analysis was performed on the R software environment and the code lines are reported in this work to fully meet the policy of open science based on data transparency, replicability for similar case study and to promote interdisciplinary discussion of the adopted method. It was developed within a three-year PhD project carried out at the Dipartimento di Scienze dell'Antichità, Sapienza University of Rome aimed at investigating the potential uses of an internal area of the fortified settlement of Coppa Nevigata (Northern Apulia, Italy), dated to the advanced Late Bronze Age (to the 12th c. BC). The work was achieved through the spatial analysis of a wide palimpsest of artefacts and bioarchaeological remains yielded by the extensive excavation campaigns.

2. The case study

The Bronze Age settlement of Coppa Nevigata (Northern Apulia, Italy) is part of the wide phenomenon that sees the rise of fortified settlements in the Central Mediterranean in the 3rd and the 2nd mill. BC. It is a reference site for the understanding of historical trajectories involving Southern Italy during the Bronze Age. In 40 years of systematic excavation large parts of the settlement have been investigated, dating from the early 2nd mill. BC to the early 1st mill. BC (19th-8th c. BC), notably those pertaining the late phase of the Late Bronze Age (12th c. BC).

During the last decades, different areas have been investigated by spatial analysis based on a conventional method, namely the mapping of functionally-determinable artefacts and ecofacts, and the visualisation of the same (Cazzella *et al.* 2002; Moscoloni *et al.* 2002). This present new analysis fits comfortably into this branch of research already carried out but adopts an up-to-date approach and focuses on a significantly larger internal area (Fig. 1A). The area concerned dates to the late phase of the 12th c. BC (Late Bronze Age), and it is located on the NE side of the settlement, where the entrance gate from the N leads into a large open space (now partially destroyed unfortunately). The study area can be divided into two subareas: the western

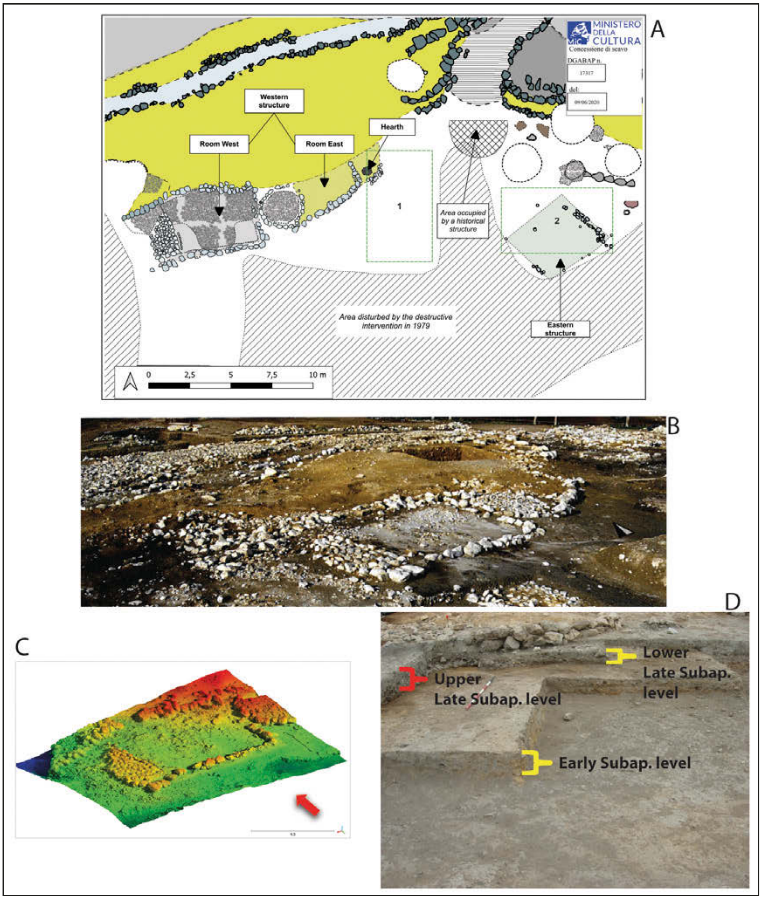

Fig. 1 – Coppa Nevigata: map of the 12th c. BC part of the settlement analysed by integrated spatial analysis (A); picture of the area under scrutiny from the W (B); photogrammetric reconstruction of the Room W of the structure (C); stratigraphic sequence of the area under scrutiny, the red curly brackets highlight the part of the deposit studied by the integrated spatial analysis (D) (Coppa Nevigata Project Archive).

one where a domestic building consisting of two adjoined rectangular rooms and a circular stone structure is present (Fig. 1B-C), and the eastern one, which encompasses a perishable structure, as witnessed by some postholes, and a stone alignment adjoining it to the N. The archaeological deposit inside the structures was poorly preserved, while the open space retained a 20 cm thick deposit resulting from the life of the structures and the contemporary use of external open spaces (upper Late Subapennine level - Fig. 1D). Despite minimal indications of a burning event, which likely involved only part of the structure, no evidence shows any major episodes of collapse or the occurrence of significant hiatus in the usage of space.

The long-lived-in dwelling space yielded thousands of refuse elements (both artefacts and ecofacts) likely resulting from activities carried out on the spot. Here, pottery fragmentation analysis (Lucci 2021) and spatial distribution analysis of single categories of remains (Lucci *et al.* 2020; Recchia *et al.* in press) has revealed that the archaeological deposit was not significantly altered by post-depositional agents, and preserved the spatial patterning of said remains. Unfortunately, on the southern edge of the study area the deposit dating to the Late Bronze Age was damaged by a destructive intervention in 1979 that completely erased the archaeological evidence, so isolating this area from the rest of the settlement.

The above is but a brief description of the study area and settlement features, since the aim of this paper is chiefly related to a methodological aspect. Further and detailed information about the archaeological contexts are provided by the widely available and up-to-date literature on the site published over the last decade (Cazzella *et al.* 2012; Recchia *et al.* 2019, 2021).

3. Materials and methods

The analysis presented in this work is based on the use of R, an extremely powerful programming language for statistics and geostatistics, which is becoming increasingly popular in archaeological research (Marwick 2018). It is an open source software environment, highly flexible and able to work with various types of data files. Based on code lines, it enables the reproduction of the analytical steps, enhancing the open science policy and interdisciplinary dialogue. In order to give the scientific community the chance to discuss, repeat and evaluate the proposed methodological approach, code lines referring to the key analytical steps are reported in this work, along with the results of such analyses.

3.1 *The spatial dataset under scrutiny*

For the area under scrutiny, finds were located by recording their spatial coordinates. In the maps, the spatial distribution and related Kernel Density of each category of remains analysed in this work are visualised (Fig. 1B). Since the goal of this paper is to provide insight into the potential of the analytical method, they represent only a part of the record of artefacts and bioarchaeological remains analysed by the integrated spatial analysis for the area under scrutiny. Faunal remains of major edible species (cattle, sheep/goat, pig, and reed deer) have been processed according to four meat-yielding categories (Barker 1982), basing on previous published work on Coppa

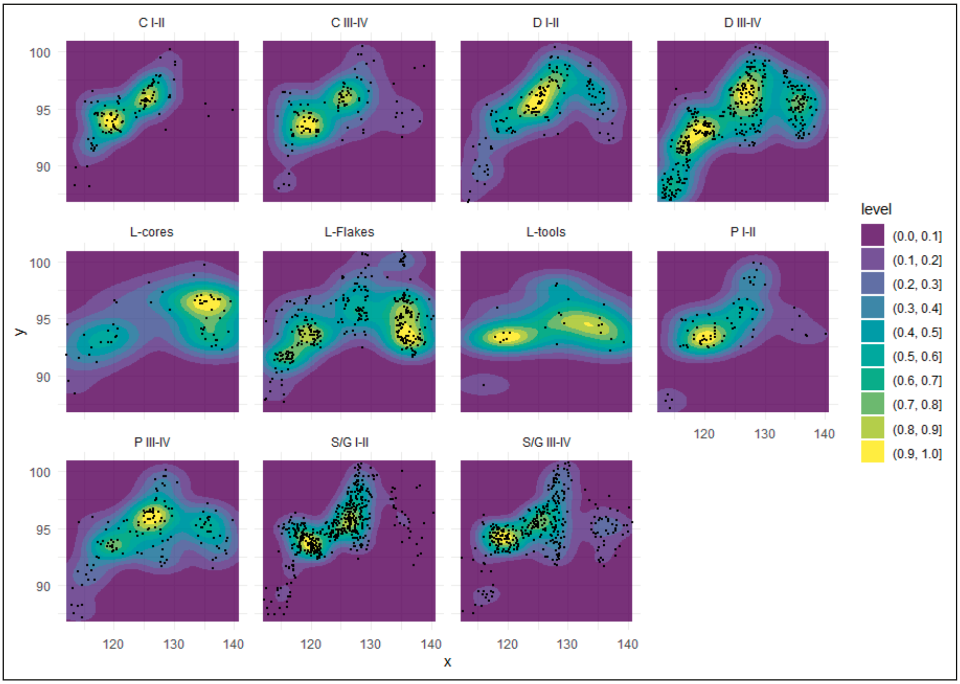

Fig. 2 – Spatial distributions of point patterns concerning lithic artefacts and faunal remains analysed in this work.

Nevigata (Bietti Sestieri *et al*. 2002; Moscoloni *et al*. 2002; Recchia *et al*. 2021) (Fig. 3A). Then, they have been divided into two main groups: the I and II classes, pertaining to torso bones and higher parts of animal legs that were considered 'good' meat-yielding portions, while the III and IV classes, pertaining to animal skulls and lower parts of legs, were considered 'low' meat-yielding portions. Conversely, lithic artefacts have been processed basing on technological categories: flakes, tools and cores (Lucci *et al*. 2020) (Fig. 3A). For the bioarchaeological remains, this analysis focuses on the fauna, as the botanical study is still ongoing and available data only partially covers square grids of the area under consideration.

Overall, the number of remains considered here is 2181, composed of 396 lithic artefacts, chiefly flakes, and 1785 faunal remains, mainly composed by caprines, both good and low meat-yielding portions (i.e. S/G I-II and S/G III-IV), and red deer remains (notably low meat-yielding portions) (Fig. 3B). More quantitative and qualitative details about the spatial dataset obtained from the area under scrutiny are published in the monograph on the PhD project (Lucci 2022) and a further paper in press (Recchia *et al*. in press).

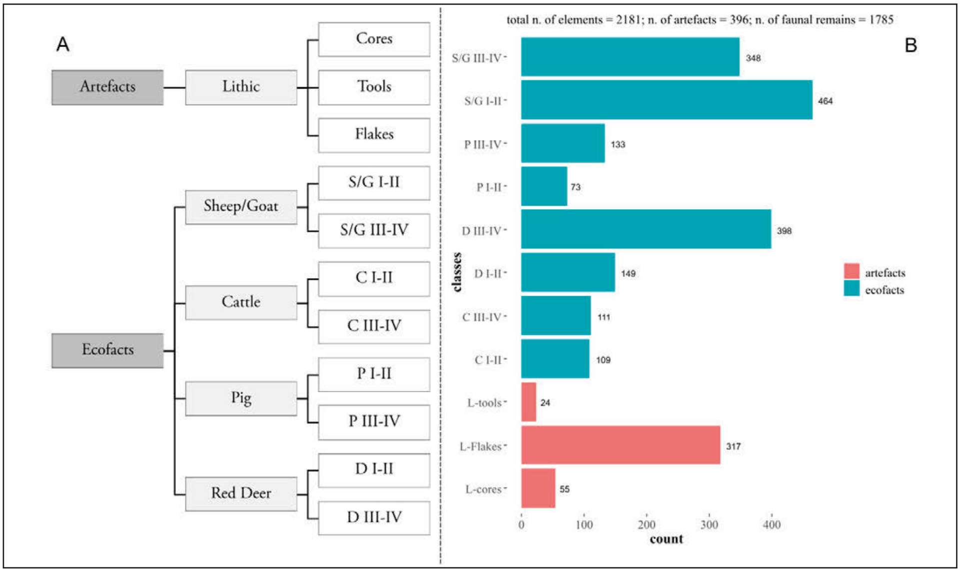

Fig. 3 – Scheme synthesising categories of remains and related functional classes processed by Gcross analysis (A); incidence of each class of faunal remains and lithic artefacts (B).

3.2 *The G-cross function in assessing spatial dependencies of pair combinations at multiple distances*

Stochastic deposit formation and alteration processes (i.e. human activity as well as post-depositional agents that alter primary distribution) can produce a combined depositional effect in a spatial perspective. For example, a distribution can appear homogeneous on a small-range scale while becoming clustered at larger scale. Ripley's K function is a technique used in Point Pattern Analysis (PPA) to assess point pattern distribution in a given area at multiple scales, counting the number of features at defined distances and testing it against a Completely Spatially Random (CSR) point pattern (Dixon 2002; Baddeley *et al.* 2015; Gelb 2022).

With regard to the dataset, to assess the distribution of each single category of remains (e.g. good meat-yield portion of cattle remains or lithic flakes), a specific univariate form of Ripley's K function, namely the variance-normalised L-function (Kiskowski *et al.* 2009), was performed: this helped the contextual understanding of their distribution (Recchia *et al.* in press). The use of the distance-based K-function was addressed to exceed disadvantages of classical methods. For example, area-based methods (e.g. Kernel Density Estimation - KDE), characterised through its first-order properties such as the spatial variation of its points' density, are unable to fully capture how things interact globally; on the other hand, the interactions of objects at different scales are not described by nearest-neighbors approaches. Ripley's K function is a technique used in PPA to assess point pattern distribution in a given area at multiple scales, counting the number of features at defined distances and testing it against a CSR point pattern (Dixon 2002; Baddeley *et al.* 2015; Gelb 2022). L-function is a commonly used transformation of the theoretical Poisson K-function which simplifies visual evaluation of the plot (Baddeley *et al.* 2015, 207). Results of this analysis are reported in Lucci 2022.

However, in this work a further analytical step is presented. After performing this operation, it was necessary to investigate if spatial aggregations between diverse categories of remains were significant: for example, if lithic flake distribution was related to the animal remains as result of butchering activities on the spot or whether they are distributed over the study area without purpose or meaning.

For this reason, I used the 2nd order Multitype Nearest Neighbour Distance Function (Gcross) for exploring whether components of two spatial point patterns were spatially aggregated or not (Stoyan, Stoyan 1996; van Lieshout, Baddeley 1999; Chiu *et al.* 2013). The Gcross is a spatial distance distribution metric that represents the probability of finding at least one given type of remains (e.g., lithic artefacts) within a radius of another given type of remains (e.g., red deer remains). These probability distributions can be applied to assess the relative proximity/association of any two types of remains. Thus, it is an effective method to assess the clustering effect of pairs of different types of remains at several distances. The resulting plot contains several curves related to the different edge-corrected outcomes of the function (i.e., the Hanisch correction, the spatial Kaplan-Meier correction, and the Border correction) against the theoretical Poisson (Gpois (r)) distribution curve. Edge corrections are used to avoid distortion of the performed function when cases along the borders of the study area are processed. Two sets of points can be considered spatially dependent if the generated curves are above the theoretical Poisson curve (the latter corresponds to independent random distributions). The analysis was performed by the function Gcross[1] implemented in the R package spatstat (Baddeley, Turner 2005). The code also included the function foreach of the R package foreach[2] for executing it in loop, in order to analyse the combination of each pair of categories composing the spatial dataset (https://rdrr.io/rforge/foreach/). Furthermore, R Markdown[3] (Xie *et al.* 2020) was used to compile the code and computing, with the aim at incorporating graphs within an organised report.

[1] https://www.rdocumentation.org/packages/spatstat/versions/1.64-1/topics/Gcross.

[2] https://cran.r-project.org/web/packages/foreach/index.html.

[3] https://rmarkdown.rstudio.com/docs/.

3.3 *The R code*

Having imported the spatial dataset as a point pattern (object of class "ppp" identified in the following code-lines as "sd"), a vector composed of the object name of each category of remains composing the spatial dataset was created. In this case, it contains names of categories of the faunal and artefact classes under scrutiny. This vector is functional for the sub-setting of all possible combination of pairs of categories of remains that are processed by the G-cross function. In this case the list of categories is composed in this way:

```
sd #spatial dataset (object of class "ppp")
Categories = c("S/G I-II","S/G III-IV","C I-II","C III-IV","P I-II",
  "P III-IV","D I-II", "D III-IV", "L-tools","L-Flakes", "L-cores")
```

At this point, the analysis may be carried out in two ways: 1) by examining the spatial relationship of a single category of remains with all the other ones, when the examination is specifically focused on a particular category; 2) by performing a cumulative analysis in which all pairs are automatically subsetted and processed. Nothing regarding the actual analysis changes; only the way the results are organised.

1) Code-lines below are referred to the first approach.

```
#to organise plotted outcomes in a grid
par(mfrow = c(2,4))
#use the function "foreach" for sub-setting from categories list
#n is the total number of elements composing the categories list
foreach(b = 1:n) %do% { #sub-set in loop the position "b"
A = Categories[n1] #A is the first element of the analysed pair
  combination
#n1 is a numeric value selected by the user to subset an element from
# the Categories list
B = Categories[b] #B is the second element of the analysed pair
  combination
#b is a numeric value previously set by the function foreach
if(a != b) { #exclude the possibility A = B
G1 = Gcross(sd,A,B) #Cross G function of the pair combination
plot(G1, main = NULL, legend = FALSE, xlim = c(0,1), ylim = c(0,1))}
  #charting result
}
```

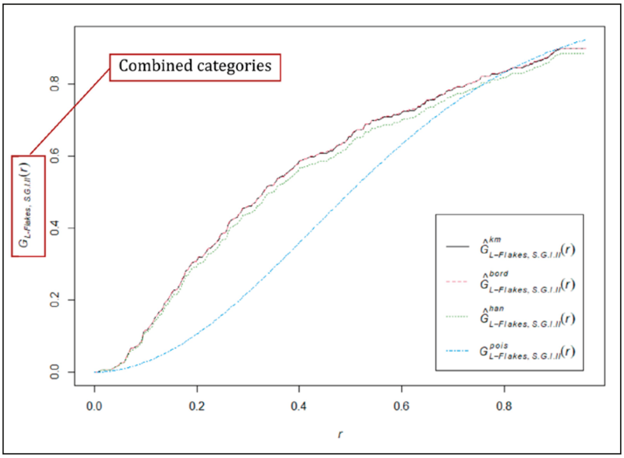

Fig. 4 – Example plot resulting from Gcross focused on two categories of remains.

The function foreach executes the subsetting process from the list of categories of remains in loop (code line 5). In this case it runs on the second element to combine, by defining "b" through the progressive selection of a number from 1 to n (where "n" is the total number of components of the Categories list). This allows one to subset an element from the Categories list, as expressed in the code-line 9 (i.e. 1 selects S/G I-II, 2 selects S/G III-IV, etc.). A (i.e. the first element selected from the Categories list) must be set by the user by a numeric value (n_1). It must be a valid index within that list (in this case between 1 and 11). For example, figuring that I want to observe combination of lithic flakes with other categories, then $n_1 = 11$. Furthermore, it is recommended excluding the possibility B = A (i.e. processing one category with itself) by imposing the condition expressed in the code-line 11.

At this point Gcross was performed and the outcomes plotted. The dotted blue curve refers to the 'theoretical Poisson process' (theo), or complete spatial randomness (CSR), whilst the other curves pertain to different edge-corrected spatial distributions (see § 3.2): Kaplan-Meier (km), Border corrected (bord) and Hanisch (han) (Baddeley, Gill 1997; Dixon 2002; Hanisch 2007). The plot's upper limit for the x axis has been set at 1 metre (xlim = c(0, 1)) and for the y axis at 1 metre (ylim = c(0,1)). The plot (Fig. 4) is an example of the resulting outcome, and it can be used to understand how to read the results of the analysis; in this example, spatial interaction between stone artefacts (i.e. flint flakes) and good meat-yielding portions of sheep/goat has been analysed. Curves pertaining to the different edge-correction estimators of the empirical distribution fall above the 'theoretical' (dotted blue) lines (which correspond to independent random distributions) from small distances until 0.8 m, when spatial correlation starts to lose significance.

It is critical to remember that outcome interpretation must take into account that the two-way relationship between pairs of point patterns is not always true (i.e., the result of Gcross of A to B might not be the same as Gcross of B to A). Here it is necessary to check both these conditions by examining the entire range of pair combinations. By adding a further code-line (i.e. G2 = Gcross (remains, B, A)), it is possible to modify the code so that it processes both plots A to B and B to A next to one another, but this will produce duplicated outcomes. Moreover, it is crucial to explore the framework of the analytical results in its entirety, not merely to consider results showing spatial associations between two categories of remains.

2) The second methodological approach entails the chance to automatically process and visualise any potential combination while avoiding any type of selection procedure. In this case, A is obtained by the same process of B (code-line 5), namely using the function foreach to progressively subset a component from the Categories list. This change only affects part of the code structure and the way in which outcomes are provided by the computing process, thus the methodological structure and result interpretations remain the same.

```
1. #to organise plotted outcomes in a grid
2. par(mfrow = c(2,4))
3. #use the function "foreach" for sub-setting from categories list
4. #n is the total number of elements composing the categories list
5. foreach(a = 1:n) %:% #sub-set in loop the position "a"
6. foreach(b = 1:n) %do% { #sub-set in loop the position "b"
7. A = Categories[a] #A is the first element of the analysed pair combination
8. #a is a numeric value to subset an element from
9. # the Categories list
10. B = Categories[b] #B is the second element of the analysed pair combination
11. #b is a numeric value previously set by the function foreach
12. if(a != b) { #exclude the possibility A = B
13. G1 = Gcross(sd,A,B) #Cross G function of the pair combination
14. plot(G1, main = NULL, legend = FALSE, xlim = c(0,1), ylim = c(0,1))} #charting result
15. }
```

3) G-cross function over different scales. The analysis was performed processing both the whole spatial dataset from the entire area under scrutiny and also focusing on smaller sample areas, in order to observe the range of outcomes and assess their reliability when figuring out the diverse use of the space in the extensive context. Notably, the analysis focused on two sample areas shown in the map (Fig. 1A), corresponding to the open space to the W of the entrance, which includes a small hearth in the NE (i.e. the Sample Area 1) and the open area and a portion of the open space with the wooden structure at the south-eastern side of the entrance gate (i.e. the Sample Area 2).

They have been selected with the sole aim of investigating the analysis outcomes of this work, but they might be tailored to meet different research issues, for example to investigate differences between an internal and an open space. In any case, it is critical that the sample areas have enough components to generate analysis results that are statistically significant. Subsetting of the point-patterns was carried out by the function owin[4] of the R package spatstat.

4. Results and discussion

110 models stemmed from each examined area (i.e., the whole space and the two sample sub-areas), enabling one to visualise and evaluate the spatial relationships between any possible pair of categories of remains. Outcomes are included in a report generated by R Markdown (Report 1[5]) and refer to the second approach mentioned in the previous section. At this point, the computerised phase of the analytical process ended. The subsequent interpretive process, in my opinion, has to revert to a heuristic dimension, led by speculative and cognitive procedures, in which the spatial connections are contextualised in the light of the archaeological and more generally social settings under consideration (Kintigh, Ammerman 1982; Hodder 1991). The accumulated outcomes show that correlations over increasing distances in numerous pairs are observed when plots concern the entire area. This results from the large quantity and density of remains throughout it. But when focusing on sample areas, the outcomes change, revealing a diversified framework of associations between pairs of combinations.

For instance, interesting information emerges on associations between lithic-flakes with faunal remains as well as with further classes of stone objects, cores and tools. As previously observed, when the entire space is examined (Fig. 5), spatial dependencies are generally strong, despite the

[4] https://www.rdocumentation.org/packages/spatstat/versions/1.64-1/topics/owin.

[5] https://github.com/enricolucci/CrossGFunction_CN/blob/85553039bf2bcaa0b2ff9f1c5c724ad1c2a335fc/Report%201%20-%20ELucci.pdf.

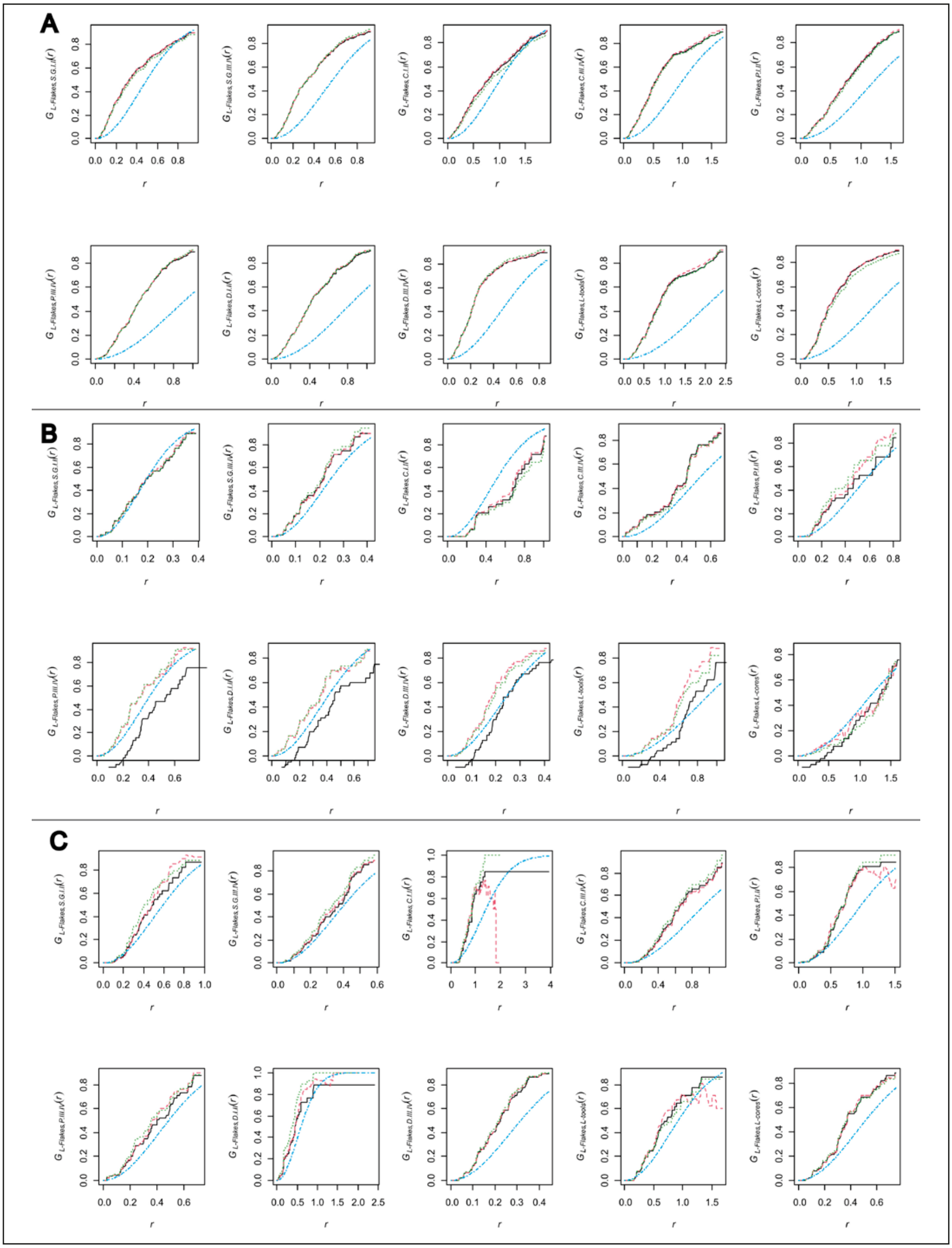

Fig. 5 – Generated plots with pairs combining point patterns of lithic flakes with those of other categories of remains. Outcomes for the entire area (A), for the Sample Area 1 (B) and for the Sample Area 2 (C).

fact that a few differences exist among plots, such as the combination of stone flakes with good and bad meat-yielding portions of caprines (S/G I-II and S/G III-IV), with the latter showing dependency at greater distances. On the other hand, analysis results for the Sample Area 1 reveal a more diversified association framework, with stone flakes generally associated with low meat-yield portions (excepting for pigs), and notably so with the deer remains, which are likewise connected to good meat-yielding portions. Integrating such outcomes with the visual interpretation given in distributional maps, published in previous and in-press papers (Recchia *et al.* 2021, in press; Lucci 2022), it has been hypothesised that the use of these open spaces was for butchering activities. This explanation seems particularly plausible when examining the red deer bones, since the faunal record contains a high quantity of limb distal extremities, which could be the result of the practice of bringing the hunted animals through the main entrance and then dismembering their carcasses right away. Moreover, the spatial relationship with stone tools is quite intriguing. The increase in G(r) values starting at roughly 0.4 m suggests that reliance is appreciable at wider distances, which is expected because the number of tool pieces is substantially lower than flakes in the examined area. In any case, it underlines the likely complimentary use of these things in this space.

Sample Area 2 yielded a further diversified framework of point patterns associations. Here, stone flakes are but weakly associated with caprine remains (both categories), but strongly associated with C III-IV and P I-II (PIII and IV are instead weakly associated) and DIII-IV. The spatial closeness of stone-flakes with low-meat-yield portions of edible species might be connected to butchering activities too. However, a further explanation appears more plausible, since this part of the study area yielded a high number of finds associable with craft production, chiefly antler/bone and metal artefacts (both ornaments and tools/implements, as well as half-processed items and raw materials). Thus, the stone flakes and tools may have been involved in the transformations of by-products (animal skins and bones). But it is also interesting to observe the strong association with stone-cores, which also suggests the potential production of flakes on the spot. As seen above, outcomes of Gcross analysis represent a valuable proxy by which to enhance the interpretation of the spatial dataset, through their integration into a wider contextual interpretive approach.

5. Final remarks

In reconstructing the activities and their organisation within a prehistoric settlement, the analysis of the spatial distribution of each category of remains is crucial, as much as the exploring of how they are spatially associated. Visual examination of distributional maps, in which artefact and bioarchaeological remains are differently characterised, is typically the most common and effective way to evaluate spatial data, notably adopting a contextual interpretive approach (Hodder 1991). On that subject, it is vital to bear in mind the observation of K. Kintigh and A. Ammerman (1982, 33) on a heuristic approach to interpreting spatial data, which «combine the intellectual sophistication of approaches with the information processing capacity and systematic benefits of quantitative treatments». In developing my PhD project, such publications significantly influenced the development of my own theoretical background. Thus, from the beginning of my work, I incorporated quantitative methods into the spatial analysis as an assistance to the interpretation of spatial datasets. In my opinion in fact, there is no other way to approach intrasite spatial analysis than the contextual analysis of functionally characterised artefacts and ecofacts (Binford 1962, 1978; Binford, Binford 1968). However, within this scientific approach to archaeological data, interpretation processes might be affected by knowledge background, experiences and even by the intuitive cognition system (Patterson, Eggleston 2017). Here, quantitative analysis supported the analytical and interpretive process, as a counterweight to cognitive bias. But modelling was confined to a specific question, adopting the approach defined as «scaffolding method» proposed by Llobera (2012).

The analysis illustrated in this work was aimed at investigating a specific question related to spatial analysis: the associations between various categories of remains, specifically how each category spatially interacted with all of the others, in the entire area under consideration as well as involving different subspaces connected to various structures. To achieve this aim, the Gcross function analysis was employed, a 2^{nd} order Multitype Nearest Neighbour Distance Function which explores whether components of two spatial point patterns were spatially aggregated or not (Stoyan, Stoyan 1996; van Lieshout, Baddeley 1999). The analysis was performed on R, a widely used opensource software environment for statistical analysis and graphics; notably the Gcross was carried out by the package spatstat. The decision to conduct the study using R was based on the intention to enable replicability of the proposed methodological approach with other contexts and promote an interdisciplinary discussion within the scientific community. On this matter, full code and dataset will be published in a future endeavour (i.e. further publications containing the entire spatial dataset analysed). Because the goal of this effort is to suggest, describe, and discuss the outcomes of a new tool among the multitude of computer instruments for analysing the spatiality of the archaeological record, only some case studies (e.g., stone artefacts and animal remains) have been examined, but any mapped type of remains can be processed.

Code lines were compiled with the aim at automatising the computing process. Moreover, the use of R Markdown (Xie *et al*. 2020) allowed us to organise plots in cumulative reports that facilitated the consulting of the outcomes. The last represented further assistance in the interpretative process of the spatial data reported on distributional maps, as already discussed in a recent work (Recchia *et al*. in press). Notably, the Gcross outcomes were particularly useful when investigating diversities of spatial relationships between pairs of categories of remains over different sub-spaces of the context under scrutiny, allowing one to enhance the understanding of the social patterns of behaviours connected to the organisation of consumption and productive activities.

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REFERENCES

Ascher R. 1968, *Time's arrow and the archaeology of a contemporary community*, in K.C. Chang (ed.), *Settlement Archaeology*, Palo Alto, National Press, 47-79.

Baddeley A., Gill R.D. 1997, *Kaplan-Meier estimators of distance distributions for spatial point processes*, «The Annals of Statistics», 25, 1, 263-292 (http://www.jstor.org/stable/2242720).

Baddeley A., Rubak E., Turner R. 2015, *Correlation*, in A. Baddeley, E. Rubak, R. Turner, *Spatial Point Patterns: Methodology and Applications with R*, Chapman and Hall/CRC, 199-254 (https://doi.org/10.1201/b19708).

Baddeley A., Turner R. 2005, *Spatstat: An R package for analyzing spatial point patterns*, «Journal of Statistical Software», 12, 1-42 (https://www.jstatsoft.org/index.php/jss/article/view/v012i06).

Barker G. 1982, *The animal bones*, in D. Whitehouse, G. Barker, G. Reece, D. Reese (eds.), *The Schola Praeconum I: The Coins, Pottery, Lamps and Fauna*, «Papers of the British School at Rome», 50, 53-101.

Bietti Sestieri A.M., Cazzella A., Baroni I., Minniti C., Recchia G. 2002, *L'Italia centro-meridionale e le isole durante l'età del Bronzo e del Ferro: aspetti metodologici*, in Peretto 2002, 321-336.

Binford L.R. 1962, *Archaeology as anthropology*, «American Antiquity», 28, 2, 217-225.

Binford L.R. 1978, *Dimensional analysis of behaviour and site structure: Learning from an Eskimo hunting stand*, «American Antiquity», 43, 3, 330-361.

Binford L.R., Binford S.R. 1968, *Archaeological perspectives*, in L.R. Binford, S.R. Binford (eds.), *New Perspectives in Archaeology*, Chicago, Aldine, 5-32.

Blanco F. 2017, *Cognitive bias*, in J. Vonk, T. Shackelford (eds.), *Encyclopedia of Animal Cognition and Behavior*, 1.6, New York, Springer, Cham.

Cazzella A., Moscoloni M., Recchia G. 2012 (eds.), *Coppa Nevigata e l'area umida alle foci del Candelaro durante l'età del Bronzo*, Foggia, Edizioni del Parco.

Cazzella A., Recchia G., Baroni I., Minniti C. 2002, *Coppa Nevigata: analisi dell'uso dello spazio in una struttura protoappenninica*, in Peretto 2002, 427-442.

Chiu S.N., Stoyan D., Kendall W.S., Mecke J. 2013, *Stochastic Geometry and Its Applications*, Chichester, John Wiley & Sons (https://onlinelibrary.wiley.com/doi/book/10.1002/9781118658222).

Dixon P.M. 2002, *Ripley's K function*, in A.H. El-Shharawi, W.W. Piegorsch (eds.), *Encyclopedia of Environmetrics*, Chichester, John Wiley & Sons, Ltd, 1796-1803.

Ferrari P.A. 2001, *Stochastic models*, in *International Encyclopedia of the Social & Behavioral Sciences*, Elsevier, 15121-15126.

Gelb J. 2022, *Network k functions* (https://cran.r-project.org/web/packages/spNetwork/vignettes/KNetworkFunctions.html).

Hanisch K.H. 2007, *Some remarks on estimators of the distribution function of nearest neighbour distance in stationary spatial point processes*, «Series Statistics», 15, 3, 409-412 (https://doi.org./10.1080/02331888408801788).

Henrickson E.F., McDonald M.M.A. 1983, *Ceramic form and function: An ethnographic search and an archeological application*, «American Anthropologist», 85, 3, 630-643 (http://www.jstor.org/stable/678663).

Hodder I. 1991, *Interpretive archaeology and its role*, «American Antiquity», 56, 1, 7-18.

Kahneman D., Tversky A. 1972, *Subjective probability: A judgment of representativeness*, «Cognitive Psychology», 3, 3, 430-454.

Kintigh K.W., Ammerman A.J. 1982, *Heuristic approaches to spatial analysis in archaeology*, «American Antiquity», 47, 1, 31-63 (http://www.jstor.org/stable/280052).

Kiskowski M.A., Hancock J.F., Kenworthy A.K. 2009, *On the use of Ripley's K-function and its derivatives to analyze domain size*, «Biophysical Journal», 97, 4, 1095-1103 (https://www.sciencedirect.com/science/article/pii/S0006349509010480).

Leonardi G. 1992, *Processi formativi della stratificazione archeologica*, in G. Leonardi (ed.), *Atti del seminario internazionale Formation Processes and Excavation Methods in Archaeology: Perspectives (Padova 1991)*, Padova, Saltuarie dal laboratorio del Piovego 3, 13-47.

van Lieshout M.N.M., Baddeley A.J. 1999, *Indices of dependence between types in multivariate point patterns*, «Scandinavian Journal of Statistics», 26, 4, 511-532 (http://www.jstor.org/stable/4616576).

Llobera M. 2012, *Life on a pixel: Challenges in the development of digital methods within an 'interpretive' landscape archaeology framework*, «Journal of Archaeological Method and Theory», 19, 4, 495-509.

Lucci E. 2021, *Understanding the effect of trampling in a spatial perspective: A case study from a long-lived-in dwelling space of the Bronze Age settlement of Coppa Nevigata (South-Eastern Italy)*, «Archeologia e Calcolatori», 32, 1, 25-42 (https://doi.org/10.19282/ac.32.1.2021.02).

Lucci E. 2022, *La distribuzione spaziale dei reperti come base per un'interpretazione dei livelli subappenninici di Coppa Nevigata (Manfredonia, FG) in termini di aree di attività*, Roma, Sapienza Università Editrice.

Lucci E., Vilmercati M., Mironti V. 2020, *Analisi della distribuzione spaziale dei manufatti in litica scheggiata da un'area interna all'abitato di Coppa Nevigata*, in A. Gravina (ed.), *Atti del 40° Convegno Nazionale Preistoria, Protostoria e Storia della Daunia (San Severo 2019)*, Foggia, Centro Grafico S.r.l., 183-204.

Marwick B. 2018, *R coding and modeling*, in *The Encyclopedia of Archaeological Sciences*, Elsevier, 1-5 (https://onlinelibrary.wiley.com/doi/full/10.1002/9781119188230.saseas0631).

Merrill M., Read D. 2010, *A new method using graph and lattice theory to discover spatially cohesive sets of artifacts and areas of organized activity in archaeological sites*, «American Antiquity», 75, 3, 419-451 (http://www.jstor.org/stable/25766210).

Moscoloni M., Recchia G., Baroni I., Minniti C. 2002, *Coppa Nevigata: analisi funzionale delle strutture subappenniniche dei settori E4 e D5 (Scavi Puglisi-Palmieri in estensione)*, in Peretto 2002, 443-465.

Patterson R.E., Eggleston R.G. 2017, *Intuitive cognition*, «Journal of Cognitive Engineering and Decision Making», 11, 1, 5-22 (https://journals.sagepub.com/doi/full/10.1177/1555343416686476).

Peretto C. (ed.) 2002, *Analisi informatizzata e trattamento dati delle strutture di abitato di età preistorica e protostorica in Italia*, Firenze, IIPP.

Recchia G., Cazzella A. 2019, *Coppa Nevigata in the wider context of Bronze Age fortified settlements of South-Eastern Italy and the Adriatic area*, in S. Hansen, R. Krause (eds.), *Bronze Age Fortresses in Europe. Proceedings of the Second International LOEWE Conference (Alba Julia 2017)*, Bonn, Habelt-Verlag, 81-97.

Recchia G., Lucci E., Fiorentino G., Minniti C., Mironti V., Primavera M., Siracusano G., Vilmercati M. 2021, *Interpreting long-lived-in dwelling spaces: Integrated spatial analysis of a late Bronze Age area at Coppa Nevigata (South-Eastern Italy)*, in L. Jallot, A. Peinetti (eds.), *Use of Space and Domestic Areas: Functional Organisation and Social Strategies. Proceedings of the XVIII UISPP World Congress (Paris 2018)*, Oxford, Archaeopress, 119-137.

Recchia G., Lucci E., Fiorentino G., Minniti C., Vilmercati M. in press, *Spaces and functions: Activities organisation in the fortified settlement of Coppa Nevigata during the Late Bronze Age*, in press.

Schiffer M.B. 1985, *Is there a 'Pompeii Premise' in archaeology?*, «Journal of Anthropological Research», 41, 1, 18-41.

Schiffer M.B. 1987, *Formation Processes of the Archaeological Record*, Albuquerque, N.M, University of New Mexico Press.

Shanks M., Hodder I. 1995, *Processual, postprocessual and interpretative archaeologies*, in I. Hodder *et al.* (eds.), *Interpreting Archaeology: Finding Meaning in the Past*, London-New York, Routledge, 3-33.

Skibo J.M. 2012, *Understanding Pottery Function*, New York, Springer New York (http://link.springer.com/10.1007/978-1-4614-4199-1).

Stoyan D., Stoyan H. 1996, *Estimating pair correlation functions of planar cluster processes*, «Biometrical Journal», 38, 259-271.

Xie Y., Dervieux C., Riederer E. 2020, *R Markdown Cookbook*, New York, Chapman and Hall/CRC (https://www.taylorfrancis.com/books/mono/10.1201/9781003097471/markdown-cookbook-yihui-xie-christophe-dervieux-emily-riederer).

ABSTRACT

Large dwelling spaces, characterised by a continuous human occupation and for different practices, represent crucial archaeological contexts in reconstructing the organisation of production and consumption activities within prehistoric communities. However, the archaeological record related to such depositional contexts often appears spatially disordered and dominated by a chaotic distribution, the result of the interaction of human and natural agencies over time. On this matter, computer modelling offers a wide range of methods to disentangle the apparent spatial chaos and assess the dynamics behind the distribution of the remains, both those deriving from human activities carried out on the spot and those resulting from later disturbances. In this framework, one of the main issues is the reconstruction of the

spatial relationships between components in the archaeological record, which may reflect a complex of materials and tools from some human activity. This paper explores the effectiveness of Gcross function analysis to investigate dynamics of interactions between different categories of remains in a large dwelling space, addressing the question of how each category of remains interacts in the space with the others. As a case study, the analysis focuses on a wide area within the Bronze Age fortified settlement of Coppa Nevigata (Southern Italy).

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DEFINING SOUTHERN ETRURIA FINAL BRONZE AGE SETTLEMENT MODELS USING AN INTEGRATED GIS AND MACHINE LEARNING APPROACH

1. Introduction

Southern Etruria has been extensively studied in recent Italian protohistory (di Gennaro 1979, 1982, 1986, 1988; Potter 1985; Negroni Catacchio 1995; Pacciarelli 2001; Belardelli *et al.* 2007; Schiappelli 2008; Barbaro 2010). In terms of historical reconstruction, this region is crucial during the transition between the Bronze and Iron Age (around 950/925 BC, Pacciarelli 2001, 67-69), when a significant change in settlement patterns occurred. The change entailed a transition from a polycentric village system, typical of the Bronze Age, to proto-urban centers (Peroni 1989, 2004; Bietti Sestieri 2010; Cardarelli 2018), sites of future Etruscan cities (Bartoloni 1989, 2012; Pacciarelli 2001, 12).The study of the last phase of the Bronze Age (Final Bronze Age, 1150-950/925 BC, Pacciarelli 2001, 67-69) in this region contributes to our understanding of the reasons for this change.

The discovery and study of these contexts (primarily settlements) have been undertaken by the Roman protohistoric school and its scholars, who have developed a comprehensive framework for historical reconstruction (Schiappelli 2008, 21-28; Barbaro 2010, 17-19). The topographical and territorial study, the position of settlements and their relationship to the surrounding area can be a valuable methodological support for the reconstruction of protohistoric society (Potter 1985, 65-106; Pacciarelli 2001, 71; di Gennaro 2010, 13-16). In this sense, digital analyses can be of valuable support: while GIS needs no introduction as its use in archaeology is almost customary by now (Scianna, Villa 2011), the application of Machine Learning (ML) is becoming more and more present in archaeology (Bickler 2021) thanks also to the availability of opensource and well-documented resources which have certainly enabled the integration of disciplines in recent years.

The aim of this paper is to propose an approach that combines GIS raster analysis with ML techniques to identify formal or quantitative characteristics of the Final Bronze Age (FBA) settlements in Southern Etruria. To achieve this goal, a specific pipeline is proposed, which includes raster morphological analyses, simulations and techniques derived from ML and data analysis. The characteristics of the FBA settlements will be defined through quantitative and reproducible raster analyses and compared with those derived from a simulation of random points within the same territory. This comparison will

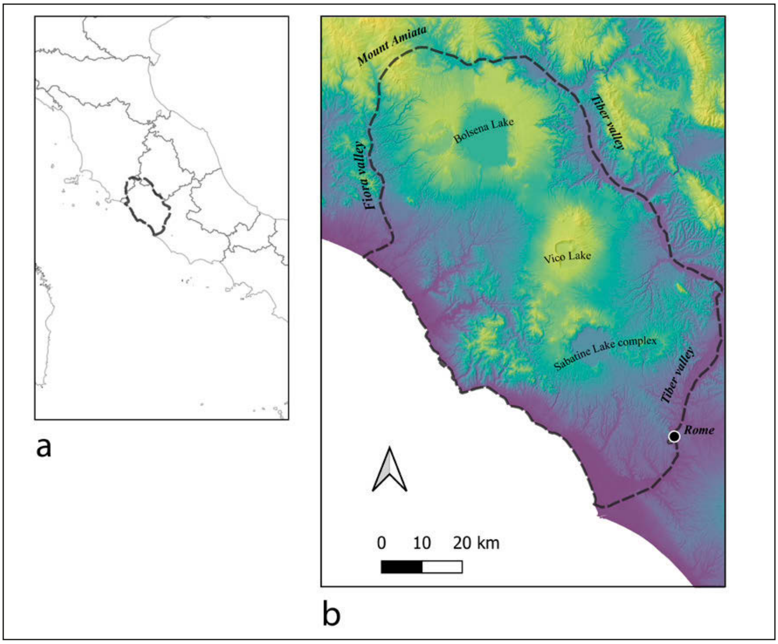

Fig. 1 – a) Territory of Southern Etruria with the current regional administrative boundaries; b) DEM of the territory of Southern Etruria. The boundaries and main geographical features mentioned in the text and the location of the city of Rome are indicated.

help us distinguish between the common characteristics in the area and those that are specific to the FBA's own settlement choices.

2. Dataset

The territory of Southern Etruria is located between the Fiora valley to the W, Amiata Mount to the N, and the Tiber River to the E and S (Fig. 1b) (di Gennaro 1986, 7-8; Barbaro 2010, 19). It mainly falls within the present-day regions of Latium, Tuscany, and Umbria (Fig. 1a). B. Barbaro (2010) comprehensively analysed evidence about the region to create a cohesive picture. She extensively collected relevant archaeological evidence, resulting in a topographical classification of settlements (Barbaro 2010, 27-35), a chronology based mainly on decorative elements (Barbaro 2010, 71-118), and an extensive catalogue of settlements, hoards, and funerary areas (Barbaro 2010, 147-330). The commonly accepted settlement pattern in the region involves sites located on plateaus with very steep flanks, which are considered an effective form of natural defence (Pacciarelli 2001, 72-74;

Barbaro 2010, 27-36). These sites are typically 5-6 km apart and cover an average of 5 to 6 hectares (Cardarelli 2018, 374).

There are exceptions to this rule, such as perilacustrian settlements or settlements located in open positions (Barbaro 2010, 33-35). However, the 'natural defenced' model is predominant: M. Pacciarelli (2001, 100) calculates that over 90% of FBA settlements (in a sample of 70 sites he analysed) are located on plateaus with very steep flanks. A. Schiappelli (2008) and B. Barbaro (2010) developed measures to quantify the 'defensive potential' of settlement contexts in their respective monographic works. In both cases, more than half of the settlements were attributed a high 'defensive potential'.

Regarding funerary practices, burials consist of cremations within biconical urns with covers. Grave goods are scarce, suggesting that the ritual followed extremely strict rules (De Angelis 2006). According to these considerations, A. Cardarelli (2018, 375) describes this territorial organization as polycentric, with villages having similar socio-political structures and governed by elites in potential competition with each other.

The sites analysed in this study were drawn from the monographic work of B. Barbaro (2010). The data used includes settlement contexts, as classified in Barbaro's work: those referred to as 'settlement' (insediamento) or 'probable settlement' (probabile insediamento) in the Barbaro 2010 classification and catalogue (Barbaro 2010, 147-330), for a total of 166 contexts (Fig. 2a). The sites were positioned as points in the UTM coordinates indicated by the author (Barbaro 2010, 150).

The analyses were performed using the Tinitaly DEM (https://tinitaly.pi.ingv.it/), a digital terrain model with a resolution of 10 m. The cells W47070, W47075, W46570, W46575 and W46075 (https://tinitaly.pi.ingv.it/Download_Area2.html) were combined into a single raster. The analysis area was generated by creating a circular buffer of 1 km around each site and using it to cut out the raster (Figs. 3, 4, 5). This resulted in a series of small, circular DEMs centred around each point. This procedure was mainly necessary to reduce the processing load without losing information by resampling the raster.

To identify the characteristics of the FBA settlements in Southern Etruria, a simulation was conducted by placing random points within the same territory. The rationale behind this approach is as follows: if there is a specific settlement pattern in this region, as proposed by numerous authors, most archaeological sites should exhibit specific attributes. However, it is important to ensure that these attributes are not merely common features shared with the surrounding territory but are indeed unique to the settlement pattern. To address this issue, a comparison with random sites was performed. These simulated sites were distributed randomly over the territory to identify common characteristics, which can be considered as a sort of background noise. This comparison allowed for the identification of unique features specific to

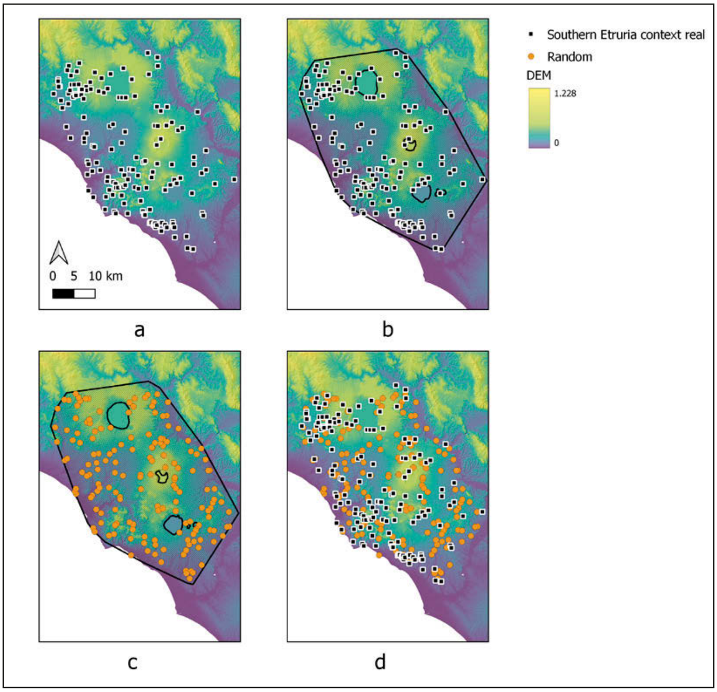

Fig. 2 – a) Position of the 166 archaeological contexts within the database; b) definition of the delimitation polygon created from the archaeological contexts; c) random points within the delimitation polygon; d) archaeological contexts and random points compared.

the settlement pattern of the FBA. To position the random points, a delimitation polygon was created relative to the real archaeological contexts and the main bodies of water, such as the Sabatine Lake complex, Lake Bolsena and Lake Vico, were excluded from the polygon to prevent random points from ending up within these areas (Fig. 2b). Thus, random points were generated amounting to the same number of archaeological contexts (166), and randomly positioned within the polygon (Fig. 2c). This method allowed for a fair comparison between archaeological and simulated sites (Fig. 2d).

3. Methods and tools

3.1 *Raster analysis*

To achieve the objectives of this study, various raster analyses were carried out to identify features that can be used as predictors in the ML algorithm (Tab. 1). These predictors, developed using the open source GIS software SAGA (https://saga-gis.sourceforge.io/), are grouped into macro-classes, including Morphometry (Fig. 3), Lighting and visibility (Fig. 4), Channels and hydrology, and Terrain classification (Fig. 5). This division allows us to organise the results of the analyses and interpret their meaning in the context of the study. Each algorithm used returns a raster grid, and the results of the analysis can be either quantitative or continuous (Morphometry, Lighting and visibility, Channels and hydrology) or categorical (Terrain classification).

To prepare the data for analysis, each point was linked to the corresponding raster value by a spatial join. This resulted in a multivariate dataset

PREDICTOR	TOOL
Morphometry	
Slope	Basic Terrain Analysis[1]
Aspect	
Relative Slope Position	
Normalised Height	Relative Heights and Slope Positions[2]
Standardised Height	
Mid-slope Position	
Terrain Ruggedness Index (TRI)	Terrain Ruggedness Index[3]
DEM	*None*
Lighting and visibility	
Visible sky	Sky View Factor[4]
Sky View Factor	
Average View Distance	
Topographic Positive Openness	Topographic Openness[5]
Topographic Negative Openness	
Channels and hydrology	
Valley Depth	Basic terrain analysis[1]
Channel Network Distance	
Topographic Wetness Index (TWI)	
Terrain classification	
TPI based Landforms	TPI based Landforms[6]
Geomorphons	Geomorphons[7]

Tab. 1 – Table showing the various raster predictors divided by macroclass. The software tool used and its documentation are given in the footnotes.

[1] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_compound_0.html.

[2] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_morphometry_14.html.

[3] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_morphometry_16.html.

[4] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_lighting_3.html.

[5] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_lighting_5.html.

[6] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_morphometry_19.html: the tool returns the following values: 1: Streams; 2: Midslope Drainage; 3: Upland Drainage; 4: Valleys; 5: Plains; 6: Open Slopes; 7: Upper Slopes; 8: Local Ridges; 9: Midslope Ridges; 10: High Ridges.

[7] https://saga-gis.sourceforge.io/saga_tool_doc/8.4.1/ta_lighting_8.html: the tool returns the following values: 1: Flat; 2: Peak; 3: Ridge; 4: Shoulder; 5: Spur; 6: Slope; 7: Hollow; 8: Footslope; 9: Valley; 10: Pit.

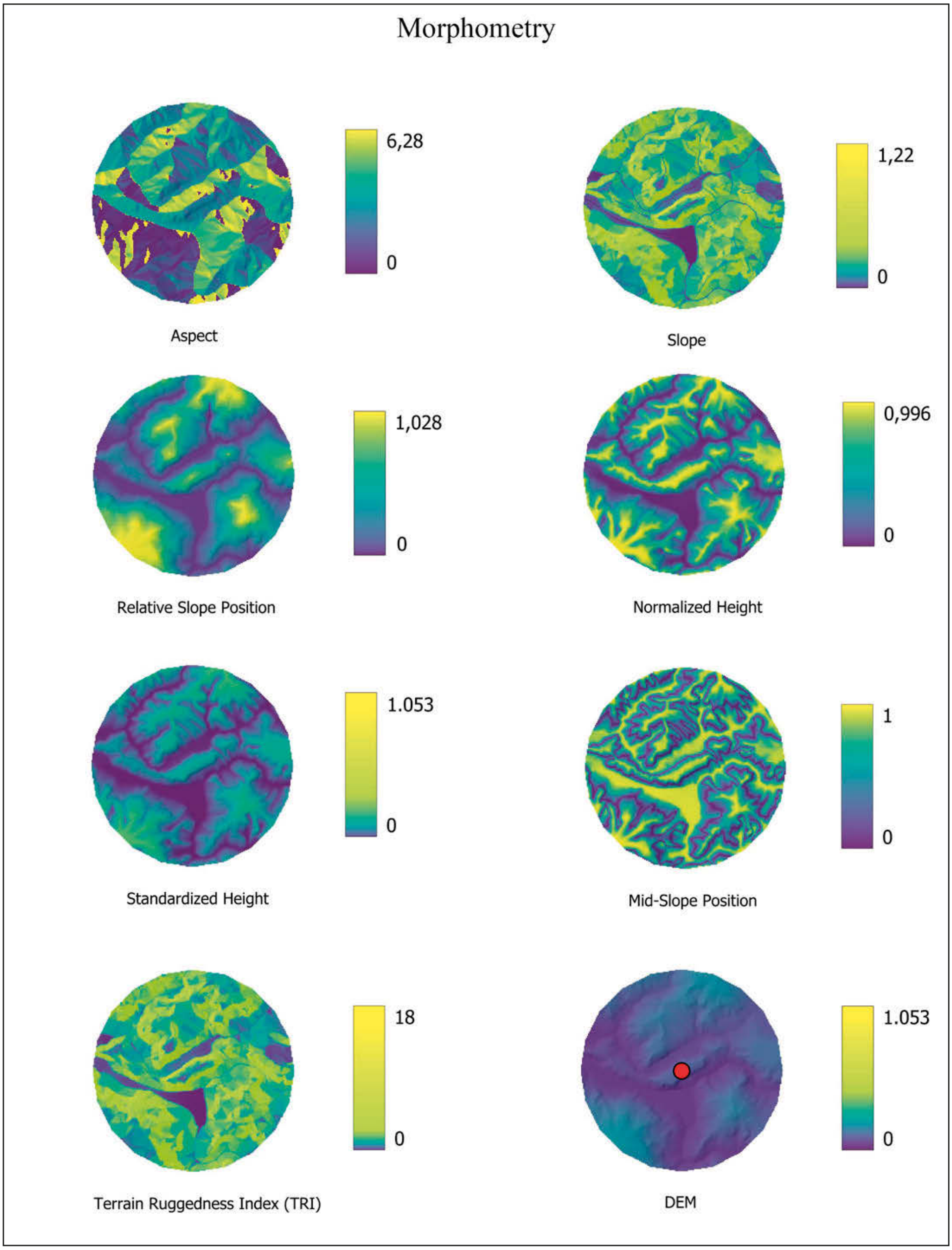

Fig. 3 – Illustration of the raster predictors related to the morphometry macro-class used for the analysis. The example context is Luni sul Mignone and the displayed area corresponds to the 1 km buffer around the site (its position is indicated by the red marker in the DEM grid).

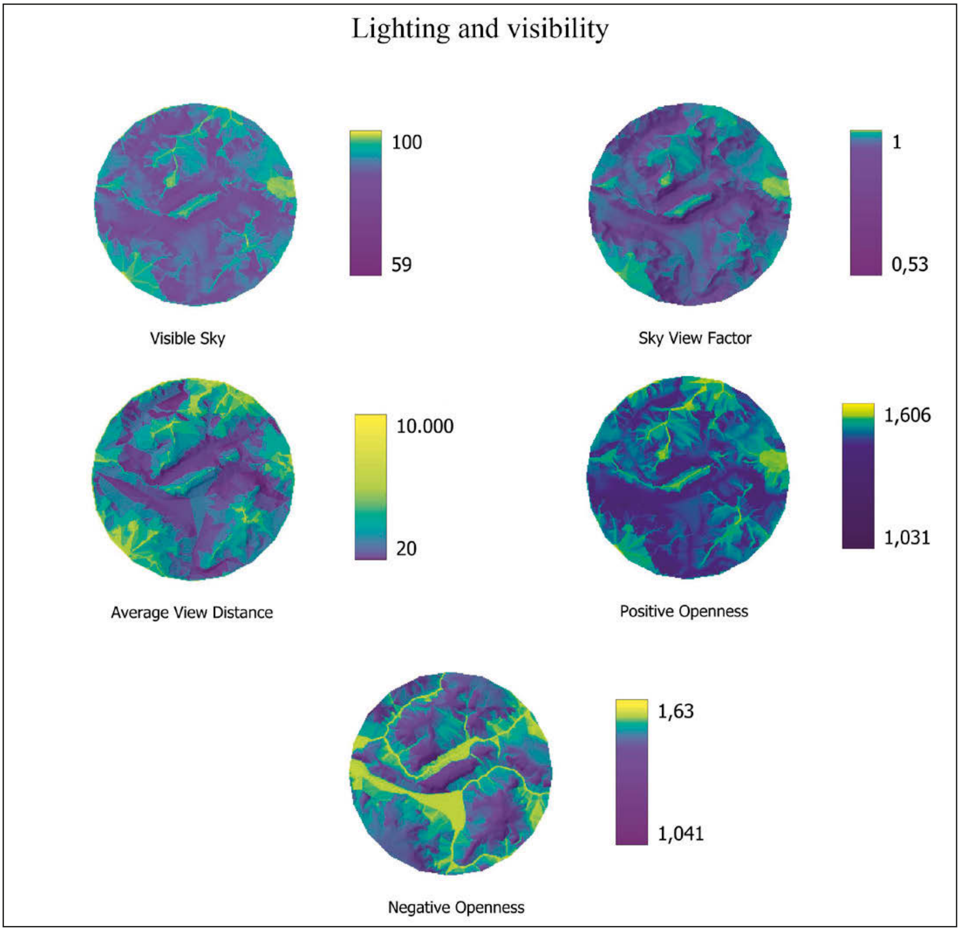

Fig. 4 – Illustration of the raster predictors related to the Lighting and visibility macro-class used for the analysis.

where each row represents a point (archaeological site or random) and each column represents a raster analysis value (Tab. 2).

3.2 *Defining most important features: a Machine Learning based pipeline*

As already mentioned in the introduction and aims of this paper, the objective of this article is to use a quantitative approach to identify morphological characteristics of settlements in Southern Etruria. To achieve this, we will use methods specific to data analysis and ML. Feature Selection (FS) is a common technique in ML that involves selecting a subset of the most relevant

index	id	name	type	Visible Sky	…	Valley Depth	TWI	TPI Landforms	Geomorphon
0	15	Sorano-Castelvecchio	real	89,30	…	54,14	2,15	9	3
1	10	Pitigliano	real	99,38	…	4,43	5,25	9	3
2	13	Monte Rosso	real	90,26	…	12,95	5,52	7	6
3	16	Sovana	real	98,91	…	3,40	6,32	9	3
4	4	Il Gaggio	real	93,63	…	68,94	6,94	4	10
5	11	Le Sparne di Poggio Buco	real	96,32	…	0,53	4,64	9	5
6	6	Meletello	real	94,13	…	18,03	4,86	6	7
7	7	Monte Tellere	real	98,94	…	0,00	3,68	10	3
…	…	…	…	…	…	…	…	…	…
324	0	random	random	98,60	…	2,04	6,18	5	4
325	0	random	random	98,04	…	3,06	6,17	5	6
326	0	random	random	95,83	…	14,17	8,90	6	6
327	0	random	random	99,36	…	2,00	9,05	5	6
328	0	random	random	98,14	…	4,39	7,54	5	6
329	0	random	random	95,49	…	12,41	7,00	6	6
330	0	random	random	96,63	…	45,67	6,65	5	6
331	0	random	random	99,22	…	42,21	13,46	5	1

Tab. 2 – Example table with some archaeological sites and random points with the values of each predictor from the spatial join operation.

features to use in the construction of a predictive model (Liu 2010; James *et al.* 2013, 204). Unlike dimensionality reduction methods, such as PCA or more recent methods like t-SNE or UMAP (Cardarelli, Lapadula 2022), FS does not create new variables, but simply selects the most important ones from the existing data. While FS is typically performed before training a model, Feature Importance (FI) is performed after training a model and it is used to evaluate the relative importance of different features in the context of a specific model (Hastie *et al.* 2009, 593-595; Saarela, Jauhiainen 2021).

To support the explanation within the text, a diagram of the proposed pipeline is provided (Fig. 6). The various steps within the procedure are indicated by a dashed box in the diagram and will be described in the following text. The application of preliminary FS (1st step, Fig. 6) involves the correlation threshold (Saeys *et al.* 2007; Van Hulse *et al.* 2012; Tang *et al.* 2014). This is a conceptually simple but powerful method for reducing redundancy and noise in the dataset: if two measures are highly correlated, it means that one of the variables can be used to predict the other. This means that, within the large number of variables in the dataset, it is possible that some of them define the same phenomenon. Therefore, within each raster macro-class, we will calculate the correlations between the variables and eliminate those that are highly correlated.

To account for the possible non-linear nature of the correlations, we will use the Spearman correlation coefficient (Spearman's ρ). This is a measure of

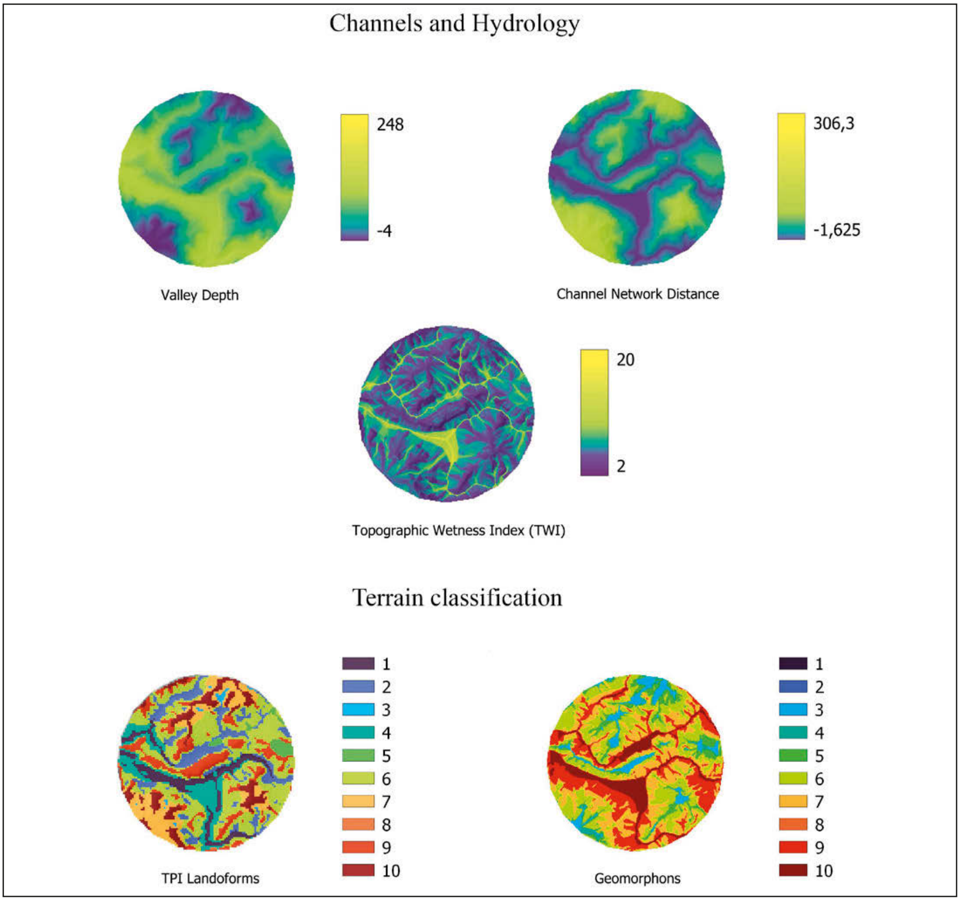

Fig. 5 – Illustration of the raster predictors related to the Channels and hydrology and Terrain classification macro-classes used for the analysis.

the statistical dependence between two variables, which considers the ranks of the data rather than the raw values (Spearman 1904; Corder, Foreman 2014, 140-145). This allows us to capture also non-linear relationships between the variables and to identify the most relevant features more accurately. The absolute value of 0.8 (i.e., ± 0.8) was chosen as the limit value, which is generally recognized as an extremely high correlation limit (Schober *et al.* 2018). As this method is based on correlation, it is not possible to apply it to categorical predictors. The second step (2nd step, Fig. 6) involves training the ML model that will subsequently be used to calculate the FI. Prior to training the model, the dataset needs to be divided into a Train Set and a

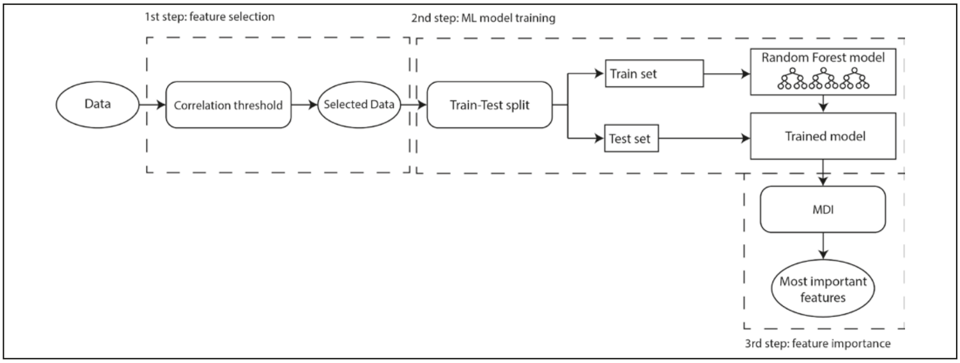

Fig. 6 – Schematic representation of the pipeline used for data analysis. The dashed boxes indicate the various steps described in the text.

Test Set (James *et al.* 2013, 176). This is a common procedure for many ML algorithms and allows the model to be trained on a significant portion of the data (Train Set - 80% of the total) before testing its performance on unknown data (Test Set - 20% of the total).

In this specific case, real and random sites are equally distributed in both the Train and Test sets, ensuring that our results are fair and unbiased. For this analysis, we have chosen to use the Random Forest model (Ho 1998). Random Forest is a ML algorithm that utilizes multiple decision trees to make predictions (Hastie *et al.* 2009, 587-603). The decision tree algorithm creates a tree-like model of decisions and their consequences by splitting the data into smaller subsets based on input variable values until a stopping criterion is met. Each node in the tree represents a decision or a test on an input variable and each branch represents the outcome of that decision or test. The leaves of the tree represent the final output or prediction (Harrington 2012, 37-60).

Although decision trees are intuitive ways to classify or label objects, they tend to overfit, i.e., memorize the training data and fail to predict new data (Harrington 2012, 39), defeating their substantial purpose. Random Forest combats this issue by combining multiple decision trees, each trained on a random subset of the data, to make the final prediction (Vanderplas 2016, 426-433). Both Random Forest and decision trees use criterions called Gini impurity or entropy (Harrington 2012, 40-43; James *et al.* 2013, 311-314) to determine how to split the data at each node in the decision tree. The goal of the algorithm is to minimize the criterion of the subsets created by each split. In this sense, a split that results in subsets with lower criterion is considered better than a split that results in subsets with higher criterion. Regarding the parameters chosen, 1000 decision trees were used in the proposed Random Forest model and the Gini impurity was chosen as criterion.

After training the model, we move to the last step (3rd step, Fig. 6), determining the FI by using data from the Test Set to identify the most important features that distinguish real sites from simulated sites. In this analysis, we use the mean decrease in impurity (MDI) method. The idea behind this method is that features that are more frequently selected for splitting are more important in predicting the target variable. For each decision tree in the forest, we can calculate the total amount of impurity (e.g., entropy or Gini, *supra*) that is decreased by splitting on a particular feature. We can then average these values across all trees in the forest to obtain an estimate of the feature importance (Hastie *et al.* 2009, 593-595). In this case, for the calculation of the FI, it was chosen to treat quantitative and categorical measures separately.

To summarize the proposed model, redundant variables will be eliminated during the initial FS step. Then, the ML model will be trained on the remaining data. The trained model will be used to calculate the most important features using the FI process, which will help to identify the most significant characteristics of the settlement pattern of Southern Etruria in the FBA.

3.3 *Hardware and software*

The supplementary material includes details on the hardware and software used, as well as the raw data in XLSX format (the table containing values resulting from spatial join between real/random site and raster analysis), along with the analysis procedure with commented code, tables, and graphs (http://www.archcalc.cnr.it/indice/suppl-material/34.2/3/Cardarelli_2023_supplementary.zip).

4. Results

The results of correlation threshold process for FS are exemplified using the visibility macro-class as an example. In this case, we can visualize the relationship between all variables using a scatterplot matrix (Fig. 7). From the scatterplot matrix, we can point out that some measures are highly correlated, such as Positive Openness and Visible Sky, which have a linear relationship. Other measures, such as Sky View Factor and Visible Sky, exhibit a non-linear relationship, such as an exponential or logarithmic relationship. Then, the correlations between the variables are quantified using the Spearman's coefficient and a matrix can be used to visualise them.

In the case of the visibility measures (Fig. 8a), the highly correlated measures (with an absolute correlation value greater than 0.8) are Positive Openness/Visible Sky, Positive Openness/Sky View Factor, and Visible Sky/Sky View Factor. Positive Openness can be eliminated because it appears twice as a highly correlated feature, and in the case of Visible Sky/Sky View Factor, it is preferable to eliminate Sky View Factor because its average correlation

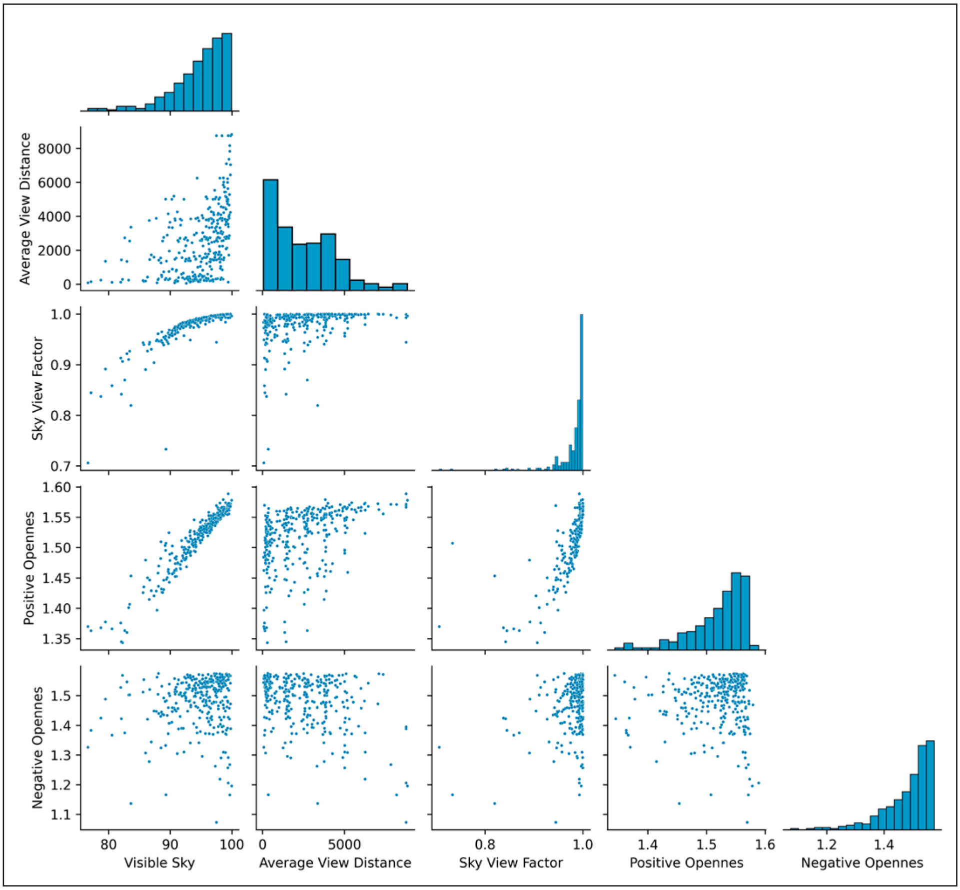

Fig. 7 – Scatterplot matrix related to the Lighting and visibility macro-class. Related measures are clearly visible. On the diagonal are histograms relating to each univariate variable.

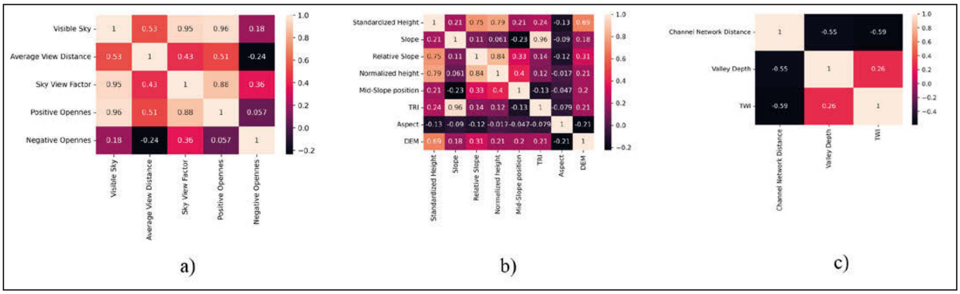

Fig. 8 – a) Correlation matrix for the Lighting and visibility macro-class; b) correlation matrix relating to Morphometry macro-class; c) correlation matrix relating to Channels and hydrology macro-class.

with the other features is higher (0.722 vs 0.724). By applying the same process to the morphometric measurements, we can identify and eliminate the features Normalized Height and Terrain Ruggedness Index (TRI) (Fig. 8b). In the case of the channels and hydrology measures, lastly, there are no highly correlated measures (Fig. 8c). As previously mentioned, this process is not applied to qualitative measures, such as those related to Terrain classification. After training the Random Forest model, we can measure model performance through accuracy, i.e., the percentage of predictions (real or simulated site) that are corrected by the model.

The model trained on quantitative data had an accuracy score of 0.65, meaning that it was able to correctly classify 65% of the data, while the model trained on categorical data obtains an accuracy of 0.71 (71%) suggesting that categorical data seems to be able to discriminate more accurately between real and simulated data. After this verification, we can finally move on to feature importance (3rd step, Fig. 6). For a better interpretation of the results, it was decided to create a random variable that serves as a threshold for importance. Features that exceed this threshold are considered important, while those that fall below it are considered random and basically insignificant within the model. In terms of quantitative measures, five features exceed and overcome the random variable threshold: Negative Openness, Mid-Slope Position, Channel Network Distance, TWI, Visible Sky, Valley Depth, Slope, Average View Distance and Relative Slope (Fig. 9a).

However, only the first four predictors were found to be effective in correctly discriminating real sites from random ones. This conclusion was drawn from boxplots that visually represented the values of the predictors (Drennan 2010, 37-41). These plots showed the difference in values between the real and simulated sites. The variables that differed markedly from the importance value obtained from the random variable (Negative Openness, Mid-Slope Position, Channel Network Distance, TWI, Visible Sky) and one below the random limit (DEM) were entered within the grid of boxplots. The predictors Negative Openness (Fig. 10, 1), Mid-Slope Position (Fig. 10, 2), TWI (Fig. 10, 3) and Channel Network Distance (Fig. 10, 4) exhibited relevant differences at the interquartile range level. On the other hand, the difference using the variable Visible Sky mainly manifested itself at the level of outliers, which were more present in the random sites, particularly with respect to low value levels (Fig. 10, 5).

The last boxplot (Fig. 10, 6) represented a variable considered unimportant (that of the DEM). The boxplots were extremely similar and overlapped, making it impossible to discriminate real sites from random ones. Based on these results, the characteristics of the real sites were identified by having lower Negative Openness values (indicating they are more topographically closed), higher Mid-Slope Position values (indicating they are further from the slopes), lower TWI values (indicating that they are located in areas sheltered from waterlogging), and higher Channel Network Distance values (indicating that they are positioned above the underlying hydrological network) than the random sites. When analysing qualitative categorical data (Fig. 9b), we need to consider each value individually within the model, rather than comparing them as we would with quantitative data. This allows us to determine which individual categories within the data are the most important, rather than trying to compare the overall importance of different data sets.

In this case, the most informative variables are TPI Landforms (Middle Ridge) value 9, TPI Landforms (Plains) value 5, TPI Landforms (High Ridge) value 10, and Geomorphon (Ridge) value 3. These categories characterise the archaeological sites, except for TPI Landforms (Plains) value 5, which appears to describe simulated sites instead (Fig. 11).

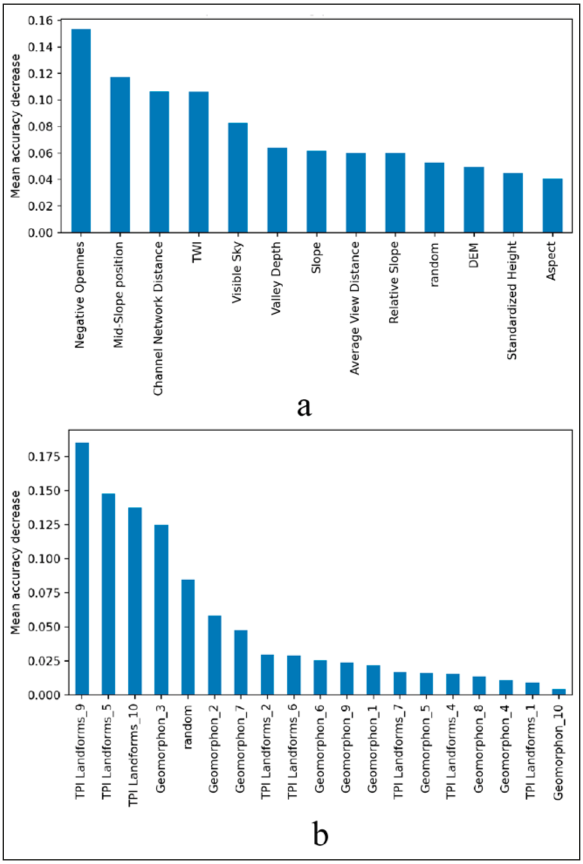

Fig. 9 – Feature importance for continuous (a) and categorical (b) values.

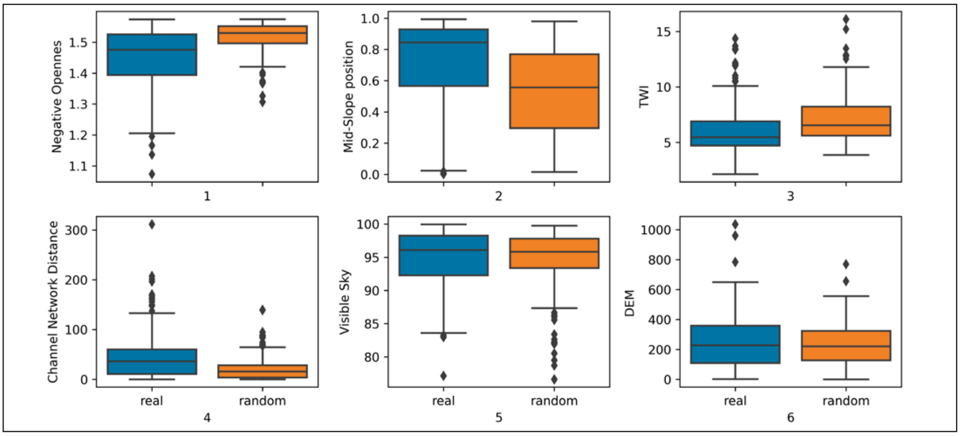

Fig. 10 – Series of boxplots showing the difference between the various 'important' continuous measurements (1-5) and 'unimportant' measure (6).

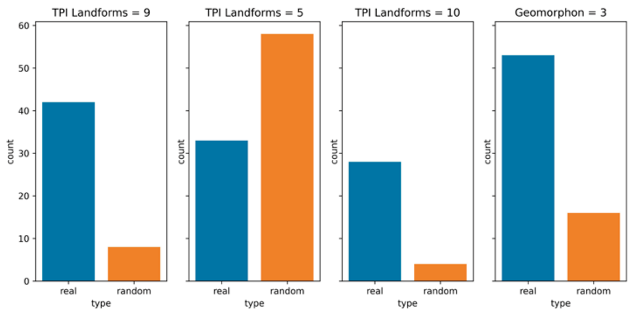

Fig. 11 – Series of bar graphs showing the number of sites per category for each 'important' categorical variable.

5. Discussion and conclusion

The creation of numerous raster predictors allows us to build a comprehensive database for the creation of objective morphologic measurements. SAGA is an excellent solution for this purpose as it is open source and offers a wide range of powerful algorithms. By integrating this raster-database with the dataset of archaeological and random contexts and using the Random Forest model and the FI process, we are able to identify the attributes that characterise the actual FBA settlements in Southern Etruria: by comparing these attributes with random points within the same landscape, we can discern the characteristics that are specific to the settlement pattern and not influenced by the overall landscape morphology. As far as the characterization of the macro-classes is concerned, the average impact of the various features is highest for the classes referring to visibility (0.097) followed by hydrology (0.090) and finally the general morphology of the territory (0.06), suggesting a strong impact of the visibility concept for the characterization of the analysed sites.

The features selected in this work can be linked to the settlement pattern model described empirically for the FBA in Southern Etruria: settlements are located in a prominent position with respect to the underlying hydrographic network (Channel network distance, TWI), are not on slope (Mid-slope position) and occupy mainly summit positions (informative variables for TPI Landforms and Geomorphons). In contrast, more intuitive measures such as altitude above sea level (DEM) do not seem to be significant factors in characterizing the settlement pattern. Specifically, the Negative Openness measure is the variable that best discriminates real from simulate site (Fig. 9a) and seems to describe extremely effectively the concept of 'defensive potential' (i.e., a closed location in landscape) described by numerous authors and considered as one of the fundamental settlement characteristics in the territory. In fact, the analyses carried out confirm that a settlement model exists, and it is generally well characterized, as the accuracy of the Random Forest model is around 70% for both quantitative and categorical data.

The quantification of such phenomenon, as well as confirming the settlement model proposed by numerous authors, allows for a broader field of investigation. For example, we can generate predictive maps of the territory using the features considered most important or take into account different targets. By using sites from a different chronological phase (e.g., those from the Iron Age) instead of random points, it is possible to identify new characteristics and features that discriminate contexts and can be used as the basis for new historical-archaeological interpretations. In this sense, combining FE and FI is a useful tool that allows us to identify and select the most important features from a dataset regarding a specific objective. In our case, we were able to reduce the number of continuous predictor variables from 14 to 4 and categorical variables from 20 to 3. This not only simplifies the interpretation of the results, but also allows us to conduct further analyses without the need for dimensionality reduction algorithms.

Obviously, the use of this pipeline is not limited to the GIS and geographical ambit but can be used as an excellent alternative to dimensionality reduction methods in any multivariate archaeological dataset.

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REFERENCES

Barbaro B. 2010, *Insediamenti, aree funerarie ed entità territoriali in Etruria meridionale nel Bronzo finale*, Firenze, All'Insegna del Giglio.

Bartoloni G. 1989, *La cultura villanoviana. All'inizio della storia etrusca*, Roma, La Nuova Italia Scientifica.

Bartoloni G. (ed.) 2012, *Introduzione all'Etruscologia*, Firenze, Hoepli.

Belardelli C., Angle M., di Gennaro F., Petitti P., Trucco F. (eds.) 2007, *Repertorio dei siti protostorici del Lazio: province di Roma, Viterbo e Frosinone*, Firenze, All'Insegna del Giglio.

Bickler S.H. 2021, *Machine Learning arrives in archaeology*, «Advances in Archaeological Practice», 9, 186-191 (https://doi.org/10.1017/aap.2021.6).

Bietti Sestieri A.M. 2010, *L'Italia nell'età del Bronzo e del Ferro: dalle palafitte a Romolo (2200-700 a. C.)*, Roma, Carocci.

Cardarelli A. 2018, *Before the city. The last villages and proto-urban centres between the Po and Tiber rivers*, «Origini», 42, 359-382.

Cardarelli L., Lapadula A. 2022, *Dimensionality reduction for data visualization and exploratory analysis of ceramic assemblages*, «Archeologia e Calcolatori», 33, 33-52 (https://doi.org/10.19282/ac.33.2.2022.03).

Corder G.W., Foreman D.I. 2014, *Nonparametric Statistics: A Step-by-Step Approach*, Hoboken NJ, Wiley.

De Angelis S. 2006, *Il passaggio tra Bronzo Finale 2 e Bronzo Finale 3 in Etruria meridionale sotto il profilo delle sepolture*, in R. Peroni (ed.), *Studi in onore di Renato Peroni*, Firenze, All'Insegna del Giglio, 581-589.

di Gennaro F. 1979, *Contributo alla conoscenza del territorio etrusco meridionale alla fine dell'età del Bronzo*, in *Atti XXI Riunione Scientifica Istituto Italiano Preistoria e Protostoria*, 267-274.

di Gennaro F. 1982, *Organizzazione del territorio nell'Etruria meridionale protostorica: applicazione di un modello grafico*, «Dialoghi di Archeologia», 2, 102-112.

di Gennaro F. 1986, *Forme di insediamento tra Tevere e Fiora dal Bronzo finale al principio dell'età del Ferro*, Firenze, L.S. Olschki.

di Gennaro F. 1988, *Il popolamento dell'Etruria meridionale e le caratteristiche degli insediamenti tra l'età del Bronzo e l'età del Ferro*, in C. Bettini, G. Colonna, R. Staccioli (eds.), *Etruria meridionale. Conoscenza, conservazione. Atti del convegno (Viterbo 1985)*, Roma, Edizioni Quasar, 59-82.

di Gennaro F. 2010, *Introduzione*, in Barbaro 2010, 13-16.

Drennan R.D. 2010, *Statistics for Archaeologists: A Commonsense Approach*, New York, Springer.

Harrington P. 2012, *Machine Learning in Action*, Shelter Island, Manning Publications Co.

Hastie T., Tibshirani R., Friedman J.H. 2009, *The Elements of Statistical Learning: Data Mining, Inference and Prediction*, New York, Springer.

Ho T.K. 1998, *The random subspace method for constructing decision forests*, «IEEE Transactions on Pattern Analysis and Machine Intelligence», 20, 832-844 (https://doi.org/10.1109/34.709601).

James G., Witten D., Hastie T., Tibshirani R. 2013, *An Introduction to Statistical Learning*, New York, Springer (https://doi.org/10.1007/978-1-4614-7138-7).

Liu H. 2010, *Feature selection*, in C. Sammut, G.I. Webb (eds.), *Encyclopedia of Machine Learning*, Boston, Springer US, 402-406 (https://doi.org/10.1007/978-0-387-30164-8_306).

Negroni Catacchio N. (ed.) 1995, *Sorgenti della Nova: l'abitato del Bronzo Finale*, Firenze, Istituto Italiano di Preistoria.

Pacciarelli M. 2001, *Dal villaggio alla città: la svolta protourbana del 1000 a.C. nell'Italia tirrenica*, Firenze, All'Insegna del Giglio.

Peroni R. 1989, *Protostoria dell'Italia continentale: la penisola italiana nelle età del Bronzo e del Ferro*, Roma, Biblioteca di Storia Patria.

Peroni R. 2004, *L'Italia alle soglie della storia*, Roma, Laterza.

Potter T.W. 1985, *Storia del paesaggio dell'Etruria meridionale. Archeologia e trasformazioni del territorio*, Roma, La Nuova Italia Scientifica.

Saarela M., Jauhiainen S. 2021, *Comparison of feature importance measures as explanations for classification models*, «SN Applied Sciences», 3, 2, 272 (https://doi.org/10.1007/s42452-021-04148-9).

Saeys Y., Inza I., Larrañaga P. 2007, *A review of feature selection techniques in bioinformatics*, «Bioinformatics», 23, 2507-2517 (https://doi.org/10.1093/bioinformatics/btm344).

Schiappelli A. 2008, *Sviluppo storico della Teverina nell'età del Bronzo e nella prima età del Ferro*, Firenze, All'Insegna del Giglio.

Schober P., Boer C., Schwarte L.A. 2018, *Correlation coefficients: Appropriate use and interpretation*, «Anesthesia & Analgesia», 126, 1763-1768 (https://doi.org/10.1213/ANE.0000000000002864).

Scianna A., Villa B. 2011, *GIS applications in archaeology*, «Archeologia e Calcolatori», 22, 337-363 (http://www.archcalc.cnr.it/indice/PDF22/AC_22_Scianna_Villa.pdf).

Spearman C. 1904, *The proof and measurement of association between two things*, «The American Journal of Psychology», 15, 1, 72-101 (https://doi.org/10.2307/1412159).

Tang J., Alelyani S., Liu H. 2014, *Feature selection for classification: A review*, in C.C. Aggarwal (ed.), *Data Classification*, New York, CRC Press, 37-64 (https://doi.org/10.1201/b17320).

Vanderplas J.T. 2016, *Python Data Science Handbook: Essential Tools for Working with Data*, Sebastopol, Ed. O'Reilly Media.

Van Hulse J., Khoshgoftaar T.M., Napolitano A., Wald R. 2012, *Threshold-based feature selection techniques for high-dimensional bioinformatics data*, «Network Modeling Analysis in Health Informatics and Bioinformatics», 1, 47-61 (https://doi.org/10.1007/s13721-012-0006-6).

Ward Perkins J.B. 1955, *Notes on Southern Etruria and the Ager Veientanus*, «Papers of the British School at Rome», 23, 44-72 (https://doi.org/10.1017/S0068246200006620).

ABSTRACT

This research aims to use quantitative and repeatable GIS techniques, as well as Machine Learning algorithms, to study the settlement patterns in Southern Etruria during the final phase of the Bronze Age (1150-950/925 BC). The region of Southern Etruria is located in present-day Latium, Tuscany, and Umbria. The study, which includes 166 settlements, focuses on identifying the morphological characteristics of these settlements by means of raster analysis. Using a Machine Learning approach, the research will compare real settlements with random points within the region to understand the specific characteristics of the settlement pattern in the landscape. The study will also examine the use of feature selection and features importance methods to select the most significant features of a multivariate dataset.

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THE SPOIL PROJECT. ASSESSING THE RATE OF EXCAVATORS' ACCIDENTAL CERAMIC DISCARD AT THE ARCHAEOLOGICAL SITE OF SIPONTO

1. Introduction

Siponto (lat. *Sipontum*) is a coastal archaeological site located in Northern Apulia (Italy) at the foot of the Gargano mountain. The Roman colony was founded in 194 BCE, although the area has been occupied since the Middle Bronze Age (Mazzei 1999; Schiavariello 2019). The city was later abandoned around the 14^{th} c. ca, with the foundation of the nearby city of Manfredonia (Laganara 2011). In September-October 2022 the site was excavated by the Universities of Bari (Dipartimento di Ricerca e Innovazione Umanistica) and Foggia (Dipartimento di Studi Umanistici), with students working simultaneously on four trenches. The excavation campaign at Siponto has educational purposes, with the aim of training university students in archaeological fieldwork methodologies[1]. This paper aims to quantify the rate of accidental discard of archaeological material during the excavation process in two of the four trenches:

– Trench I: an area of 20×20 m, with excavators working in a single room of 7,6×6,5 m. The trench is located in the NE corner of a rectangular block of the former Roman city, where a medieval building (11^{th} c. ca) has been discovered.
– Trench IV: an area of 15×25 m. The trench is located in the southern area of the Roman and medieval city, where a district that includes a probable public building is under investigation.

The first aim of this research was to provide educators with more information about the pottery that might be accidentally most discarded and subsequently improve future tutorials on ceramic classification. The second objective was to track how much information is lost during excavation because of excavator bias. As Graesch (2009) points out, there are still few archaeological reports that consider inter-operator bias in the collection of archaeological data. The assumption is that the sample collected in the field is by default representative of the entire population. More work on the issue of inter-operator bias has been published for archaeological surveys, but rarely precautionary measures are put into practice by team leaders because of time

[1] The archaeological campaign has been directed by professors Roberto Goffredo and Maria Turchiano (University of Foggia - Dipartimento di Studi Umanistici), and Giuliano Volpe (Università di Bari - Dipartimento di Ricerca e Innovazione Umanistica) in accordance with the Ministero della Cultura - Soprintendenza Archeologia Belle Arti e Paesaggio for the provinces of Foggia and Barletta-Andria-Trani and with the Direzione Regionale Musei Puglia - Parco Archeologico di Siponto.

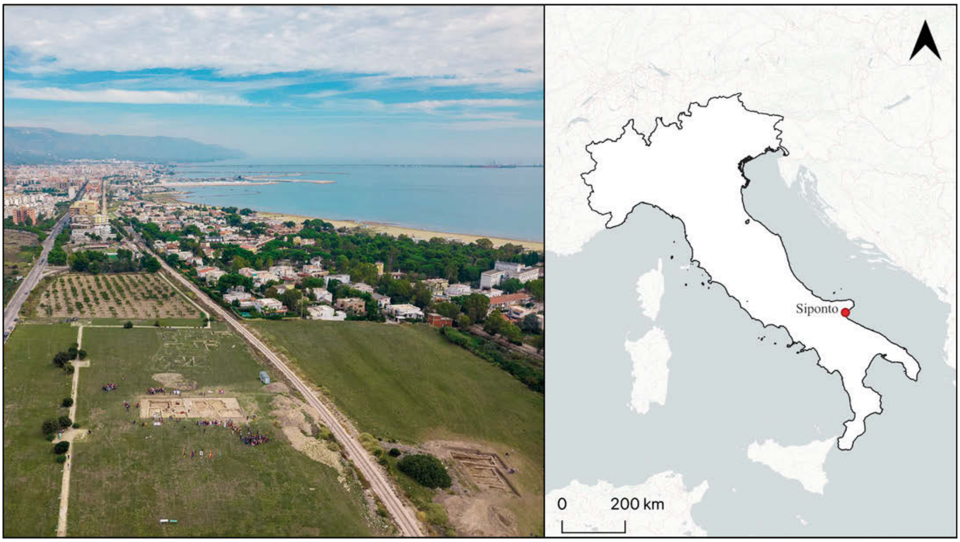

Fig. 1 – In the picture, the archaeological site of Siponto, Italy with Trench I (in the middle) and Trench IV (bottom-right). On the right side, the location of Siponto in Italy (images by the Author).

and resource constraints (Beck, Jones 1989; Hawkins *et al.* 2003). Personal preferences or arbitrary decisions of excavators can result in misleading interpretations and reconstructions of on- and off-site dynamics and temporal trends. Considering the growth of quantitative studies in Italian archaeology, a more rigorous approach is required during the data acquisition phase (Fig. 1).

Studying the discard variability and bias is fundamental, as post-excavation quantification of archaeological materials can be distorted by several factors occurring at the time of the collection. For instance, it can be useful to determine which part of a vessel is mostly discarded as it might be the part most subject to fragmentation or harder to recognise. If an archaeological artefact is highly present in a site, can it be the result of a personal preference or easiness of recognition by the excavator? As Dibble *et al.* (2005, 317) pointed out: «[…] all excavations suffer from bias because it is impossible to collect every object originally present in a site».

Although this is true, it is nonetheless possible to direct the excavators' attention to aspects that might impact their practice of collecting archaeological material in the field. The authors recognised how the early 20th-century excavation at La Ferrassie (France) had negatively impacted their understanding of the Mousterian lithic industry, as the original excavators only retained large, retouched stone artefacts which represented only 2-3% of the original assemblage (Dibble *et al.* 2018).

The choice of a random approach in the collection of samples for this research is due to its preliminary nature, thus studying the behaviour of every operator on the field was not possible. Even if other types of archaeological material are considered, this study mainly focuses on ceramics. Bones, metals, glasses and small finds are reported as a presence/absence variable. The following section will provide an overview of the methodology used in this paper, which discusses the variables and statistical analyses performed on the dataset. The third section will present the results of this study, suggesting how different soils, weather conditions, time and sherds colours influence the accidental discard rate of ceramics (and other archaeological materials) on the spoil heap. The last section discusses these results, including final remarks.

2. Methodology

This experiment was conducted in two trenches at the archaeological site of Siponto, where 32 students at different levels of university education were working in September-October 2022. Most of the students were enrolled in a BA course (57%), others were starting or completing a MA degree (28%) and 14% of the excavators were PhD students. The students were instructed to dump their spoil onto a designated test heap several times a day for 17 working days. The experiment was conducted on two separate trenches, resulting in the creation of two separate test heaps for this purpose. The test heaps were located away from the general spoil heap to prevent any mixture of soil. To further ensure that the soil from the test heap remained separate from previous samplings, the area of the test heap was cleaned daily before excavation began and samples were collected immediately after the soil was discarded. To ensure randomness in the investigation, soil was collected from every context excavated during each day of fieldwork, excluding stratigraphic units that contained large stones (such as collapse layers) that would have been difficult to sieve. The collection of material may be less accurate in these layers and the spoil was deposited separately on the general spoil heap and not sampled.

The samples retrieved from the test heaps ranged in size between 8 kg and 18 kg, with an average of 10.88 kg (SD = 1.82). Each bucket has been weighted using a portable luggage scale. To create a completely normal excavation environment, students were not aware of the experiment, although each student was instructed to save any piece of pottery (and other archaeological material) before dumping the soil. Whenever possible, students who had finished working on their context were placed in other areas of the excavation trench, to minimise the individual impact on the ceramic collection during the phases of shovelling, trowelling, wheelbarrow check, and layer cleaning. In addition, students took turns in carrying out these tasks. After the collection, samples have been air sieved with a mesh of 2 mm (Fig. 2a). At the end of

Fig. 2 – Sieving and recording phase: a) the sieve used for the experiment; b) examples of sherds collected during excavation.

the experiment, 59 samples have been collected, totalling 642 kgs. The total number of sherds collected after sieving was 1086.

3. The variables

The sherds have been counted and classified at the moment of sampling, in a spreadsheet that included several variables listed below.

3.1 *Date and weather conditions*

The variables related to time and weather were included to keep track of how many samples were collected daily and how the time and weather conditions affected sherds recognition:

– date: date of the spoil dump and collection of the sample, in the format day/month/year;
– time: hour in which the sample has been collected. The sampling occurred as close in time as possible to the hour of the dump;
– weather conditions: weather conditions under which the spoil has been dumped on the heap. This field was filled with two values, sunny or cloudy. Rain has not been included as the excavation stopped whenever the rain was too heavy.

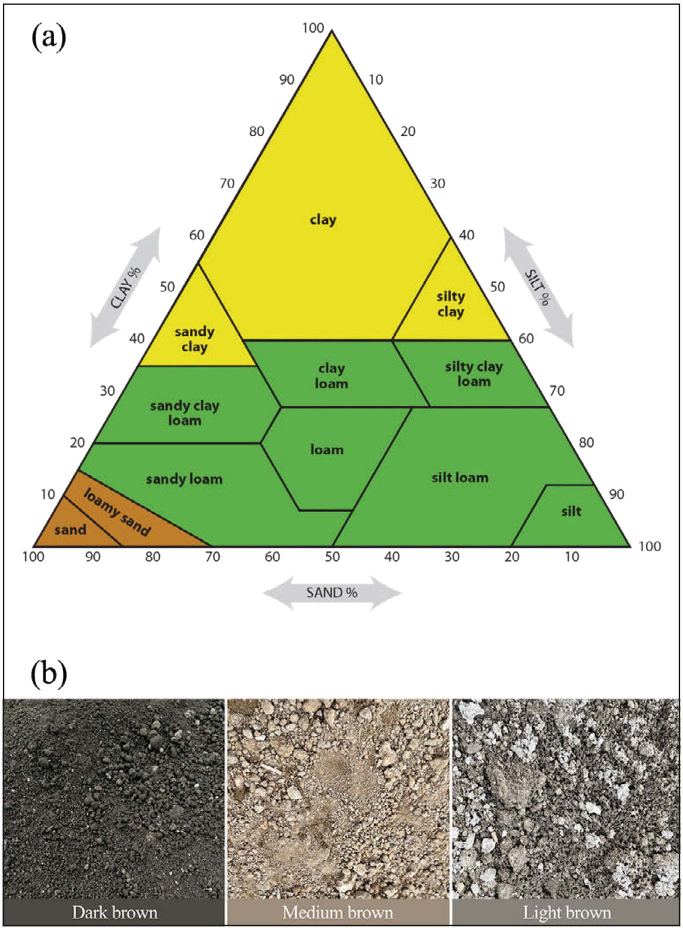

Fig. 3 – Soil types and colours. a) The archaeological soil triangle. [Legend] brown = coarse-textured soils, green = medium textured soils, yellow = fine-textured soils (from Ritchey *et al.* 2015); b) examples of soil colours of the samples collected.

3.2 *Sample attributes*

The sample variables describe the characteristics of the soil collected for each sample:

– sample: unique progressive number identifying the collected sample;
– sample_size: sample size measured in kg;
– sample_composition: composition of the sample collected (Fig. 3a), recognised by touch (Ritchey *et al.* 2015):

– sand: large particle size, with a low water-holding capacity and large porosity. It is light brown;
– silt: sediment material with an intermediate size between sand and clay and a dust-like texture. It has a good water-holding capacity and medium porosity. It is generally greyish in colour;
– clay: very fine particle size, with a high water-holding capacity and very low porosity. It is reddish-brown and can be dark brown when more loamy. Clay is heavy and dense. When wet, it is sticky and plastic. Despite clay was considered as a variable, it has been excluded from this research as the layers excavated did not provide adequate amounts of this soil type;
– loam: soil composed of sand, silt and clay in variable quantities.

– sample_colour: colour of the soil sample collected (Fig. 3b). This field was filled with three values: dark brown, medium brown, light brown;
– humidity: humidity of the soil sample collected (dry or wet).

3.3 *Sherds attributes*

The variables to store information concerning the sherds were:

– sherds_id: the absolute count of identified sherds in each sample;
– 0_2cm, 2_4cm, 4_6cm, 6_8cm, 8_10cm, over_10cm: ranges of sizes of the sherds collected after sieving. The field was filled with the counts of sherds in each range per bucket;
– grey, yellow, orange, red, green, black, multicoloured: ranges of colours of the sherds collected after sieving. The field was filled with the counts of sherds in each range per bucket;
– rim, neck, wall, base, handle: ranges of body parts of the sherds collected after sieving. The field was filled with the counts of sherds in each range per bucket.

3.4 *Presence of other archaeological material*

Extra fields were created to list the presence or absence of other archaeological materials retrieved after sieving the sample. Since the experiment focused on pottery, the fields were filled with presence/absence values – bones_present, metal_present, glass_present, and small_find. Whenever a small find was retrieved (e.g. a coin), it was reported in the notes.

4. Exploratory data analysis

The variables introduced in the previous section were used to explore the dataset and assess which are the factors influencing the accidental discard of pottery on the spoil heap. Additionally, the ratio of lost diagnostic sherds (pieces that enable the identification of certain characteristics of the original vase) to the sample weight was calculated to ensure comparability within each sample. This ratio was used for several of the variable groups mentioned in the previous section.

As measures of central tendency (mean, median) and statistical hypothesis testing are commonly used in archaeology (Drennan 2010), this section will focus on explaining Correspondence analysis and linear regression. All the calculations were performed using the statistical software R.

4.1 *Correspondence analysis*

Correspondence analysis (henceforth CA) is a dimensionality reduction technique that can be applied to contingency tables of categorical variables. CA maximises the degree of correspondence between rows and columns (i.e. observations and variables). The distance matrix used to perform the analysis is obtained from the chi-square distance between the rows and columns profiles. An in-depth methodological breakdown of CA is beyond the scope of this text, and readers can refer to Greenacre (2021). The algorithm tends to place larger abundances towards the centre of the diagonal, and small or zero values away from the diagonal, which is why outliers were removed prior to the analysis. CAs are usually visualised through biplots showing the two axes that explain the most variance in the dataset. Since the horizontal axis explains the most variance, the horizontal distances between points are more important than the vertical ones. As the distances between points are chi-squared distances, for the interpretation of the results row points closer together are more similar, and the same logic applies to column points. However, one should be careful when interpreting distances between row and column points, as they follow precise rules:

– If the angle formed by the lines connecting the row and column labels to the origin is small, the association is strong.
– If the angle is 90°, there is no association.
– If the angle is near 180°, the association is negative.
– Points away from the origin and the edges are the most informative, as they might represent a better ordination.

The R implementation of CA used in this paper is the function CA() included in the package FactoMineR (Lê *et al.* 2008). CA was applied to assess the influence of the colour of the soil on the discard of certain colours of sherds.

4.2 *Linear regression*

Linear regression is a useful approach when studying the relationship between an independent (X) and a dependent variable (Y). It is called linear as it is represented by a line on a scatterplot. The line is straight when $Y = aX$ and the slope is determined by the coefficient a. The easiest case to plot is $a = 1$, so that will be equal to any value of *X*. If the line does not pass from the origin of the graph, an additional constant, the intercept (*b*) is added to the equation: $Y = aX + b$. The logic behind linear regression is to predict the behaviour of a variable from known sets of values. The accuracy of the behaviour of the line can also be studied, but a thorough explanation of residuals and best-fit straight lines is beyond the scope of this paper. The reader can refer to texts as Shennan (1997) and Drennan (2010).

For this paper, linear regression was used to assess if time variables had an influence on the accidental discard rate of ceramic. The R function lm() was used both to look at the relationship between the hour of the day and the ratio of discarded pottery and between the date and the discard ratio. For the regressions both diagnostic and non-diagnostic sherds have been considered.

5. Results

This section presents the results of the analysis previously described. Sherds have been discarded mostly in the range of 0-2 cm (70.44%) (Tab. 1a), with a mean rate of diagnostic pieces retrieved from the samples of 30%.

Sherd size	%
0-2 cm	70.44
2-4 cm	20.62
4-6 cm	7.36
6-8 cm	1.38
8-10 cm	0.18

a

Sherd color	Quantity	%
Grey	376	34.5
Yellow	240	22
Orange	337	31
Red	59	5.4
Black	53	4.8
Multicolored	18	1.6

b

Tab. 1a-b – a) Size ranges of discarded sherds; b) colors of discarded sherds.

5.1 *Influence of the colour of the soil on the sherds discarded*

Analysis of the data allowed inferences to be drawn about the colours of the sherds (Tab. 1b) most closely related to each other and of the colours of the sherds most frequently correlated with different soil colours. The CA in Fig. 4 reveals a strong association between multicoloured ceramics and light brown soils. In the layers excavated so far in the trenches under examination, the polychrome vessels are mostly 13th century glazed productions typical of the area including the so-called RMR (ramina, manganese, rosso = copper/manganese/red) and protomaiolica types (Cuomo di Caprio 2007; De Venuto *et al.* 2015; Giorgio 2016; Valenzano 2018). The creamy colour of the fabric of these types may have enhanced the potential for sherds to be lost in light-coloured soils. However, the polychrome pieces retrieved from the samples were scarce (mean = 1.57%), possibly suggesting a good degree

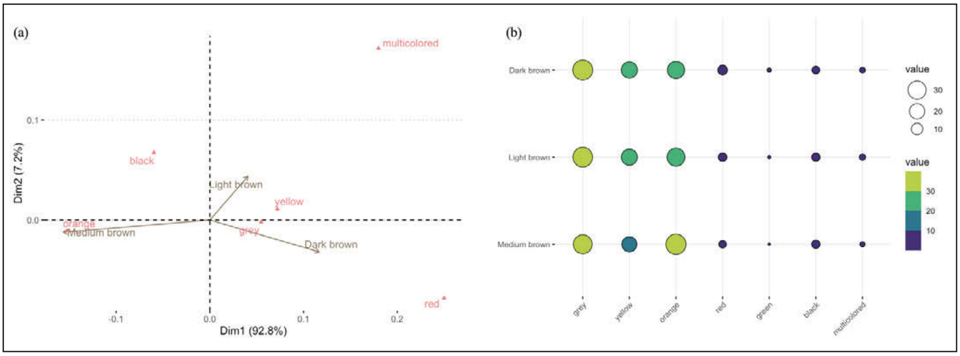

Fig. 4 – Plots showing the influence of the colour of the soil on the colour of the most discarded sherds: a) CA biplot; b) baloonplot showing the association between sherds and soil colours.

of recognition by the students. The graph also shows how red sherds can be hard to recognize when excavating dark brown soils, whereas the association with orange vessels is negative (i.e. these sherds are possibly easier to be recognised when the soil is dark). Grey and yellow sherds have similar discard rates, being the most frequently discarded, and slightly more easily found in light brown soils. Another strong link was found between medium brown soils and orange sherds. Black sherds are not strongly associated with any soil colour. Medium brown and dark brown soils are the most negatively correlated colours, as they are associated with the complete range of sherds colours.

5.2 *Influence of humidity, soil composition and weather conditions on the discard rate*

Weather conditions can impact excavators' ability to visually identify sherds before discharging the soil. The boxplots in Fig. 5 illustrate how in cloudy conditions it is much easier to lose diagnostic fragments when digging in wet soil than in dry soil. Conversely, in sunny conditions, the number of diagnostic sherds lost is higher in dry soils. The only exception was found for sandy soils, under sunny conditions the number of lost fragments is higher in wet soils. In general, the highest number of diagnostic sherds was lost in silty soils (ratio = 0.53), followed by loamy soils (ratio = 0.50) and sandy soils (ratio = 0.43).

In addition to soil colour, the humidity of the soil also affects the visibility of certain colours of sherds. From the barplots in Fig. 6, it is evident how grey, orange and yellow sherds are the most discarded. At Siponto, these colours mostly refer to common-ware pottery. In dry samples, the most discarded sherds are grey (>40%), while in wet samples orange sherds are prevalent (also >40%). This difference can be ascribed to differences in the colour of

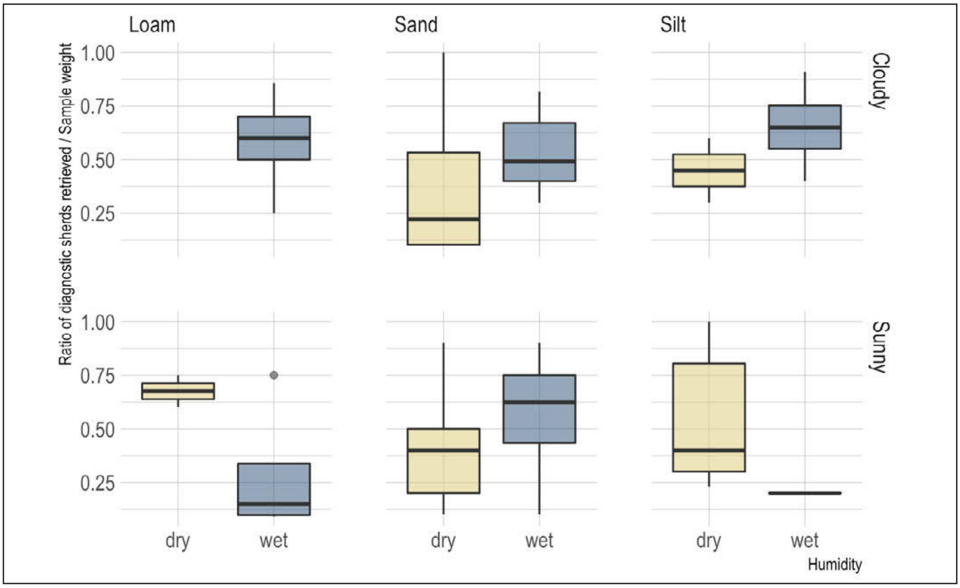

Fig. 5 – The boxplots show the diagnostic discarded sherds from dry and wet soil samples, in cloudy and sunny conditions. The results are plotted for different types of soils, although loamy soils did not provide any dry sample.

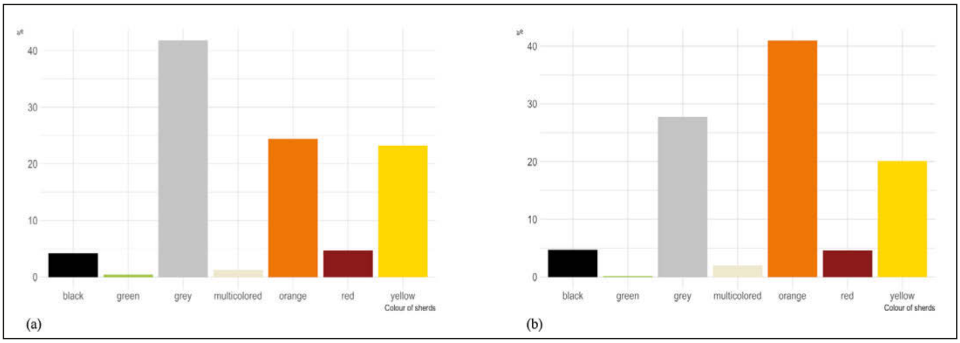

Fig. 6 – Barplots showing the percentage of the colours of the sherds retrieved both in dry and wet samples: a) dry samples; b) wet samples.

wet and dry soils. Fig. 7 shows how wet soils are mostly dark and medium brown, whereas dry soils are mostly light brown.

Sunny or cloudy conditions can also impact the visual recognition of the colour of the sherds. Grey, orange and yellow samples (common-ware pottery) are mostly discarded in both weather conditions, whilst orange sherds on cloudy

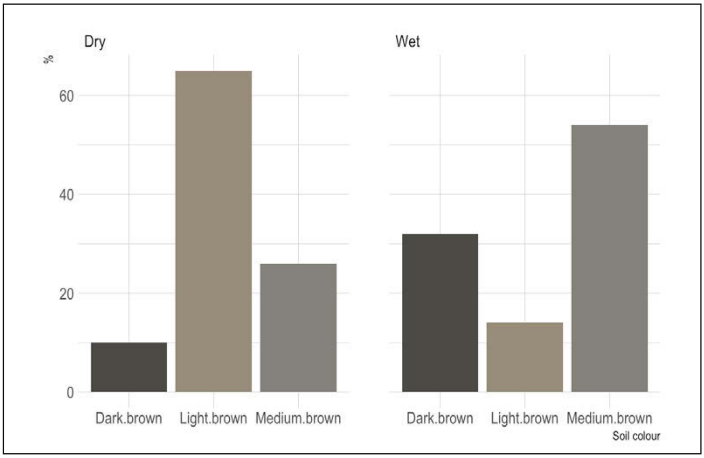

Fig. 7 – Barplots showing the percentage of colour of samples in dry/wet conditions.

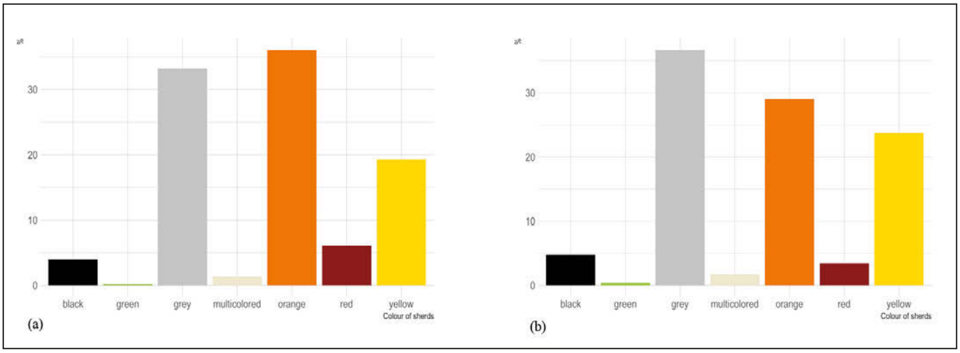

Fig. 8 – Barplots showing the percentage of the colours of the sherds retrieved under cloudy or sunny weather conditions: a) cloudy; b) sunny.

days and grey sherds on sunny days (Fig. 8). Overall, more diagnostic sherds are lost in cloudy conditions (ratio = 0.52) rather than sunny weather (ratio = 0.44).

5.3 *Diagnostic sherds*

The vessel body parts recorded during the sampling are rim, neck, wall, base, and handle. Recording which parts have been identified was important for two reasons. The first was to understand which vessel parts are less likely to be identified by students. Secondly, this data could be compared to the amount of discarded non-diagnostic pieces. Only 30% of the sherds recovered were diagnostic. The remaining 70% of the sherds could not be visually attributed to any part of the vase, and the discard might have been a deliberate choice. The most discarded body part in the dataset is the wall, which reports a median value of 60%. The part that was best recognised by students was the base (median = 17%).

5.4 *Influence of time on the discard rate*

This experiment also considered time as a factor in the discard rate of sherds in the spoil heap. Three were the main questions behind the choice of this variable:

1. Does the day of excavation have an influence on the discard rate?
2. Does the hour of the day have an influence on the number of sherds retrieved from the samples?
3. Do students get better at evaluating diagnostic ceramic sherds?

The reason for the first two questions was to evaluate if tiredness can be a significant factor impacting on the discard of archaeological material, assuming that the total number of samples was comparable. To answer the first question, I first calculated the ratio between the total number of sherds retrieved in a single sample and the weight of the sample, to allow comparability. After, I used the R function lm() to calculate the linear regression between the sherds ratio and the excavation day. The p-value was > 0.05, thus rejecting the hypothesis of students accidentally (or intentionally) discarding more sherds in the last days of excavation. In order to check if the time of the day influenced the discard rate (question 2), the samples were first divided into two categories: morning (8 AM-1 PM) and afternoon (1 PM-5 PM). After subsetting the dataset, the means of the discard ratio (calculated as above) were computed for both categories.

Time	Mean	Normality (Shapiro-Wilk)
Morning	1.66	Normal distribution, $p = 0.30$
Afternoon	1.73	Normal distribution, $p = 0.26$

Tab. 2 – Means of the morning and afternoon ratio of sherds discard in the samples.

The means show a slight increase in the discard rate in the time between the lunch break and the end of the working day. The normality of the distributions of morning and afternoon samples was calculated using the Shapiro-Wilk test (Yazici, Yolacan 2007), with a p-value higher than >0.05. Since the samples had normal distributions and the F-test showed that there is no significant difference between the two variances (p = 0.89), the means of the two categories were compared using the Welch Two Sample t-test (Welch 1947).

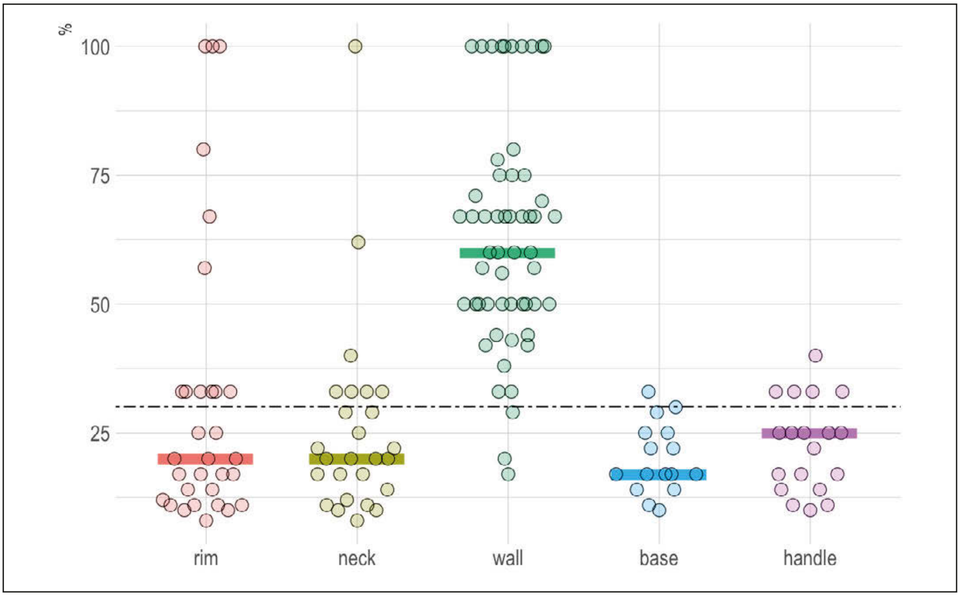

Fig. 9 – The circles in this graph show the abundance (in %) of vessel parts that have been retrieved for each sample. The coloured horizontal line indicates the median value for each group, while the black dashed line shows the mean rate of diagnostic pieces discarded on the test spoil heap.

The test rejected the hypothesis of a significant difference between the two means, hence suggesting that there is no significant daily trend in the discard.

The last question regarding changes in the rate of discarding diagnostic ceramic sherds over time was whether students were discarding fewer of these sherds as the archaeological campaign progressed. In other words, if students improved their ability to visually recognise sherds that could be useful for the subsequent quantification and interpretation of the archaeological layer. The data was divided by week of excavation, but the means (Tab. 3) only weakly support the hypothesis that students improved their ability to recognize diagnostic sherds. The highest rate of discarding was in Week 1, followed by a decrease in Week 2 and then an increase in Week 3. Further statistical analysis is needed, but the increase in Week 3 could be due to fatigue in the final stages of the excavation.

Week of excavation	Mean ratio of diagnostic sherds
Week 1	0.53
Week 2	0.37
Week 3	0.46

Tab. 3 – Mean ratio of discarded diagnostic sherds for each week of excavation.

5.5 *Other archaeological material*

This study also analysed the presence of other types of archaeological material in the test spoil heaps. The results showed that bones, particularly small/bird bones, were present in almost every sample. This is a well-known phenomenon studied by Payne (1972), who showed that sieving can significantly impact the relative proportions of faunal remains, particularly for bird bones and microfauna. Casteel (1972) also demonstrated how different mesh sizes can affect the faunal composition of a site.

Material	Presence
Faunal remains	**53**/59 (89.8%)
Glass	**24**/59 (40.6%)
Metal	**20**/59 (33.8%)
Small finds	**5**/59 (8.5%)

Tab. 4 – Presence or absence of other archaeological materials in the samples.

Metal (mostly nails) and glass were present in almost half of the samples (Tab. 4). Small finds, including three coins, a metal plaque, and a worked bone, were retrieved from 8.50% of the samples. Glass fragments, found in 24 samples (out of 59) were predominantly discovered in light brown dry soils (Fig. 10a), while metal fragments were found in 20 samples, both light brown dry soils and medium brown wet soils (Fig. 10b). Currently, it is not possible to make inferences regarding the soil type, humidity, or weather conditions that have an impact on the discarding of small finds due to the limited data.

6. Discussion and conclusions

This research conducted at the site of Siponto, Italy, aimed to investigate the degree of variability in students' accidental ceramic discarding during the 2022 archaeological campaign. The findings revealed that most of the pottery sherds lost on the spoil heap had a size ranging from 0 to 4 cm and sherds larger than 6 cm (in length) were much less frequent. Although the students were instructed to collect every pottery fragment found during the excavation, it is possible that they actively decided to discard small pieces or pieces that they deemed non-diagnostic. Whether this was a deliberate decision, the margin of error turned out to be rather high, with 30% of the ceramic materials collected from the sampling being diagnostic. This figure has implications for the subsequent quantification of ceramic classes in the laboratory. The destructive nature of the archaeological method means that the information lost can no longer be recovered, especially considering that this was a blind and randomised experiment and it is not possible to rectify the quantifications

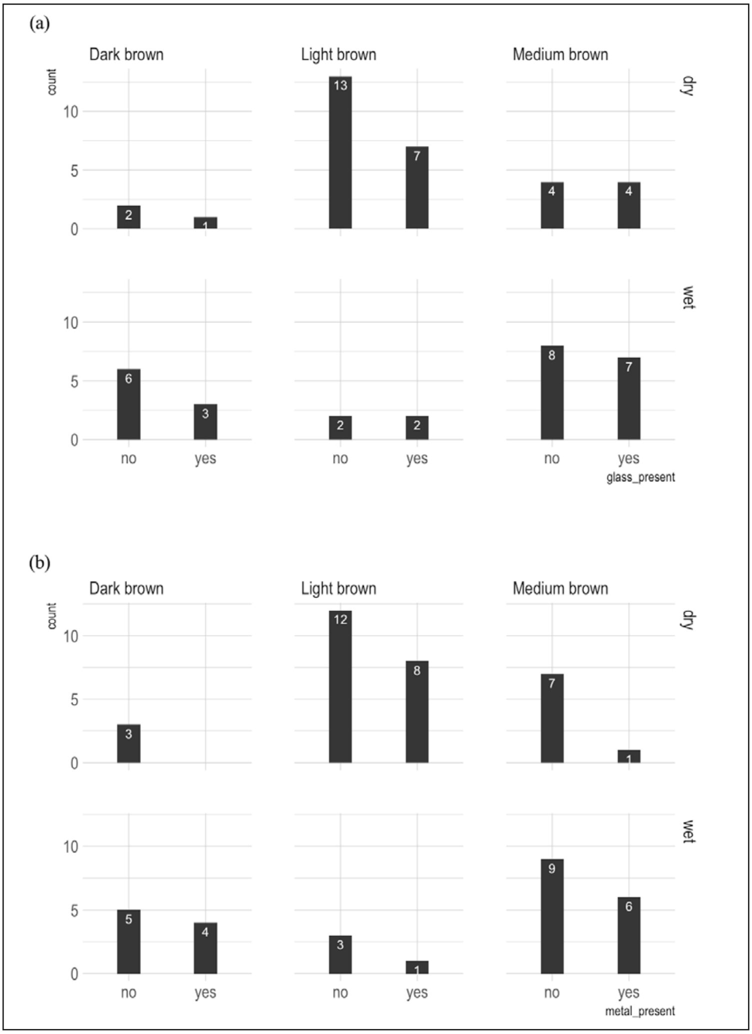

Fig. 10 – Presence of glass and metal in the samples against soil type and colour: a) glass; b) metal.

of the layers excavated. On the positive side, the second implication of this information is that it provides direction for repeating this experiment in the future, making it important to focus on improving students' training prior to future excavations. Subsequently, the degree of improvement can be analysed.

After studying the amount of information lost in the spoil heap, the study also aimed to identify the variables that may have contributed to accidental discarding. A colour-matching CA of the soil and sherds provided a better understanding of what material may be lost under certain conditions. For instance, red sherds were mostly lost in dark brown soils. Measures of central tendency were used to evaluate which soil types, colours and weather conditions influence the loss of ceramic fragments. For example, on cloudy days it is easier to lose fragments in any kind of damp soil, and orange fragments are the most easily discarded. The diagnostic parts of the vessels recovered from the samples were also quantified, with the walls being the most commonly lost.

Finally, the research focused on time variables to determine whether they were important factors in the discard rate. It was of interest whether tiredness (physical or mental) influenced the students' behaviour during the excavation and whether the students improved their skills throughout the excavation. Linear regression and statistical hypothesis verification tests failed in this assessment, suggesting that time was not an important factor in the accidental discard. However, the average percentage of discarded diagnostic fragments seems to decrease slightly after the first week. This was a preliminary survey which would have required more time or people to record more variables for each sample, thus it was only possible to report whenever other archaeological materials (bones, metals, glasses and small finds) were also detected in the samples. The high presence of faunal remains in 89.8% of the samples may reflect conscious or unconscious student selection practices on the field.

Although the sieve mesh (2 mm) used in this study is still large for the discovery of certain classes of bones (e.g. fish bones), the introduction of the practice of dry sieving for a few samples in each stratigraphic unit would not take too much time away from the excavation and would provide important information for the study of microfauna, still largely under-studied in many Italian archaeological contexts.

These insights will be useful for the quantification of the fauna present at Siponto. In the future, these types of archaeological materials will also be quantified and cross-tabulated with the other variables used in this study. It will also be important to move from a randomised approach to a spatial one to study in which contexts we are mostly losing information. The dimensions of the stratigraphic units and the individual excavating actions will also be used as factors. This will allow to test whether there is a positive correlation between the number of collected sherds in the unit and the number of discarded ones. Further methods to quantify observer bias (Fish 1978) also need to be discussed and introduced in future campaigns. As Ian Hodder (1999, 83) noted: «interpretation occurs at the trowel's edge». It is worth asking ourselves how much our interpretation of the layers we are excavating influences our practices on the field, are we as careful and attentive when we work on collapses, wastepits or cleaning mosaics?

The study was useful for educators in identifying the types of pottery that students have difficulty recognizing, and in arranging more specific training to address these issues in future lab sessions. University excavations have educational purposes for many students each year. Checking and refining the students' learning progression is an integral aspect of the educational process, and the aim of the future excavation campaign is to minimize the amount of diagnostic pieces that are accidentally discarded and to direct the students' focus towards factors that may impact their recognition of archaeological material.

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REFERENCES

Beck C., Jones G.T. 1989, *Bias and archaeological classification*, «American Antiquity», 54, 244-262 (https://doi.org/10.2307/281706).

Casteel R.W. 1972, *Some biases in the recovery of archaeological faunal remains*, «Proceedings of the Prehistoric Society», 38, 382-388 (https://doi.org/10.1017/s0079497x00012172).

Cuomo Di Caprio N. 2007, *Ceramica in archeologia, 2: Antiche tecniche di lavorazione e moderni metodi di indagine*, Roma, L'Erma di Bretschneider.

De Venuto G., Goffredo R., Totten D.M., Ciminale M., De Mitri C., Valenzano V. 2015, *Salapia: Storia e archeologia di una città tra mare e laguna*, «Mélanges de l'École française de Rome. Antiquité», 127, 1 (https://doi.org/10.4000/mefra.2719).

Dibble H.L., Lin S.C., Sandgathe D.M., Turq A. 2018, *Assessing the integrity of older archeological collections: An example from La Ferrassie*, «Journal of Paleolithic Archaeology», 1, 179-201 (https://doi.org/10.1007/s41982-018-0010-1).

Dibble H.L., Raczek T.P., McPherron S.P. 2005, *Excavator bias at the site of Pech de l'Aze IV, France*, «Journal of Field Archaeology», 30, 317-328.

Drennan R.D. 2010, *Statistics for Archaeologists: A Common Sense Approach*, New York, Springer.

Fish P.R. 1978, *Consistency in archaeological measurement and classification: A pilot study*, «American Antiquity», 43, 86-89 (https://doi.org/10.2307/279635).

Giorgio M. 2016, *Storie [di] Ceramiche 2 - Maioliche "arcaiche". Atti della seconda giornata di studi in ricordo di Graziella Berti a due anni dalla scomparsa (Pisa 2015)*, Sesto Fiorentino, All'Insegna del Giglio.

Graesch A.P. 2009, *Fieldworker experience and single-episode screening as sources of data recovery bias in archaeology: A case study from the Central Pacific Northwest Coast*, «American Antiquity», 74, 759-779 (https://doi.org/10.1017/s0002731600049040).

Greenacre M. 2021, *Correspondence Analysis in Practice*, Boca Raton, Chapman and Hall/CRC.

Hawkins A.L., Stewart S.T., Banning E.B. 2003, *Interobserver bias in enumerated data from archaeological survey*, «Journal of Archaeological Science», 30, 1503-1512 (https://doi.org/10.1016/s0305-4403(03)00051-7).

Hodder I. 1999, *The Archaeological Process: An Introduction*, Oxford, Blackwell.

Laganara C. 2011, *Siponto: archeologia di una città abbandonata nel Medioevo*, Foggia, C. Grenzi.

Lê S., Josse J., Husson F. 2008, *FactoMineR: An R package for multivariate analysis*, «Journal of Statistical Software», 25, 1-18 (https://doi.org/10.18637/jss.v025.i01).

Mazzei M. 1999, *Siponto antica*, Foggia, C. Grenzi.

Payne S. 1972, *Partial recovery and sample bias: The results of some sieving experiments*, «Papers in Economic Prehistory», 1, 49-64.

Ritchey E.L., McGrath J.M., Gehring D. 2015, *Determining soil texture by feel*, «Agriculture and Natural Resources Publications», 139 (https://core.ac.uk/download/232575664.pdf).

Schiavariello G. 2019, Sipontum, in R. Cassano, M. Chelotti, G. Mastrocinque (eds.), *Paesaggi urbani della Puglia in età romana: dalla società indigena alle comunità tardoantiche*, Bari, Edipuglia, 125-139.

Shennan S. 1997, *Quantifying Archaeology*, Edinburgh, Edinburgh University Press, 2nd ed.

Valenzano V. 2018, *La ceramica medievale in Capitanata: Produzione e commercio tra l'XI e il XV secolo*, Bari, Edipuglia.

Welch B.L. 1947, *The generalization of 'Student's' problem when several different population variances are involved*, «Biometrika», 34, 28-35 (https://doi.org/10.1093/biomet/34.1-2.28).

Yazici B., Yolacan S. 2007, *A comparison of various tests of normality*, «Journal of Statistical Computation and Simulation», 77, 175-183 (https://doi.org/10.1080/10629360600678310).

ABSTRACT

This article aims to quantify the rate of accidental ceramic discard on the archaeological site of Siponto (Italy), where in 2022 the University of Bari and the University of Foggia conducted fieldwork and training for students at different education levels (BA to PhD). The goal was to identify and quantify factors leading to the accidental discard of ceramic sherds by excavators on the spoil heap. As a pilot project, a few variables have been considered to count the minimum number of individuals found after sieving soil composition and colour, weather conditions, time variables, sherds size, colour, and vessel part. Other categorical or presence/absence variables have also been considered. This enlightening investigation shows the bias in post-excavation quantification of ceramic finds. Results indicate that 30% of the fragments of pottery retrieved from the spoil heaps, used in this experiment, were diagnostic. The study also helps the educators on-site to identify the types of vessels that might be less clear for the students.

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INTEGRATING POINT PATTERN ANALYSIS AND LOGISTIC REGRESSION APPROACHES FOR EXPLORING THE SETTLEMENT PATTERN OF THE VERSILIA AND GARFAGNANA MOUNTAINS IN ROMAN TIMES

1. Introduction

Mountain archaeology has a long tradition of study and in recent years new methodologies and theories for studying these landscapes have emerged, also thanks to the widespread development and use of digital technologies for the management of big datasets. Archaeologists have regained interest in this type of environment (Tzortzis *et al.* 2010a) and, over the years, the number of studies investigating highlands with multiscale and interdisciplinary approaches has increased considerably, shedding new light on the dynamics of mountain's communities (Della Casa 2010; Carrer 2013; Migliavacca *et al.* 2021; Visentin, Carrer 2017). Roman archaeology has long underestimated the phenomenon of organising, managing, and settling highland areas, focusing more on the rural settlements in the lowlands, such as farms and *villae*. Nevertheless, interest in settlement dynamics of mountain territories has increased in recent years (Mocci *et al.* 2010).

Renewed efforts aimed at systematically acquiring new data using traditional methodologies or developing new collection methodologies have been more rarely accompanied by a review and digitization of legacy data. Since 2011, the MAPPA Laboratory of the University of Pisa has developed a set of tools for digitizing and managing archaeological legacy data (Anichini *et al.* 2012), starting from the urban area of Pisa and then progressively expanding the area of interest to cover a large part of northern Tuscany. Two recent projects focused on the analysis of the cities and territories of Pisa and Lucca in Roman times have systematically collected, digitised, and managed legacy data, both published and preserved in the Superintendencies' archives. On each side, the lack of systematic investigation in the vast mountainous territories of Versilia and Garfagnana emerged, despite traces of evanescent frequentations seem to indicate a settlement pattern of undoubted interest.

Nevertheless, some studies have had the great merit of recovering and contextualising isolated finds – often the result of random discoveries – in a broader framework, relating them to major urban centres, road infrastructures, and silvo-pastoral agricultural practices (Menchelli 1991; Ciampoltrini 2003, 2006; Fabiani 2006). Similarly, human-environment relationships in historical times have been studied, especially focusing on the plains (Bini *et al.* 2020). So far, however, this territory has never been analysed as a whole, a geo-referenced picture of the archaeological record was missing, and the lack of specific analyses of the settlement-environment relationship prevented from identifying and explaining large-scale settlement patterns. It is therefore this gap that the present study will attempt to fill, integrating the results of Point Pattern Analysis and Logistic Regression approaches to evaluate settlement dynamics in relation to this specific environment, and finally create a predictive map. Indeed, spatial and computational analysis help to identify patterns in big and diverse datasets and are used to assess representativity and biases in data. Statistical methods and predictive modelling can be used to mitigate these biases and restore realistic images of the human-environment dialectic in the formation of mountain landscapes (Kempf, Weaverdyck 2023).

2. Background

2.1 *Study area*

The study area comprises the mountain district of Versilia and Garfagnana (Lucca, north-western Tuscany) (Fig. 1). Versilia is a territorial district in north-western Tuscany between the Apuan Alps mountain ridge and the Tyrrhenian coast, bordered to the N by the Seravezza River and to the S by Forte del Motrone, although usually the territory also includes the Camaiore basin and the coastal plain extending to Viareggio. The narrow plain is morphologically homogeneous and gently sloping towards the sea, generally standing at elevations slightly above or below zero. The coastal ridge of the Apuan Alps and Mount d'Oltre Serchio reaches higher altitudes in the N, up to 900-1000 m, and progressively less marked towards the S, where it is around 200-400 m. The reliefs delimit the Versilia plain with steep slopes or wide alluvial conoids at the downstream outlet of the numerous streams. Most of the watercourses are torrential (Versilia, Cinquale, Camaiore Ditches, Motrone, Viareggio Canal), and relatively few are not overly affected by seasonal variations in rainfall, such as the Frigido River, Serchio River, and Magra River (Devoti *et al.* 2003, 73-76; Fabiani 2006, 19). Garfagnana stretches from the eastern ridge of the Apuan Alps to the crest line of the Apennine and between the Magra valley to the N and the plain of Lucca to the S.

From a geomorphological point of view, the eastern Apuan ridge is characterised by extensive rock formations of terrigenous nature that have produced less marked slopes than the Versilia side (Carmignani *et al.* 1978). The hydrographic evolution of the Serchio River passed through a Plio-Pleistocene fluvial-lacustrine phase with the development of intravalley plains where the resumption of erosive phenomena on alluvial deposits gave rise to vast terraced forms (Boccaletti *et al.* 1980; Castaldini *et al.* 1998, 416-417).

The highest peaks are concentrated in the northern part: to the W, Mt. Pisanino (1947 m), Mt. Cavallo (1895 m), and Mt. Tambura (1891 m), while

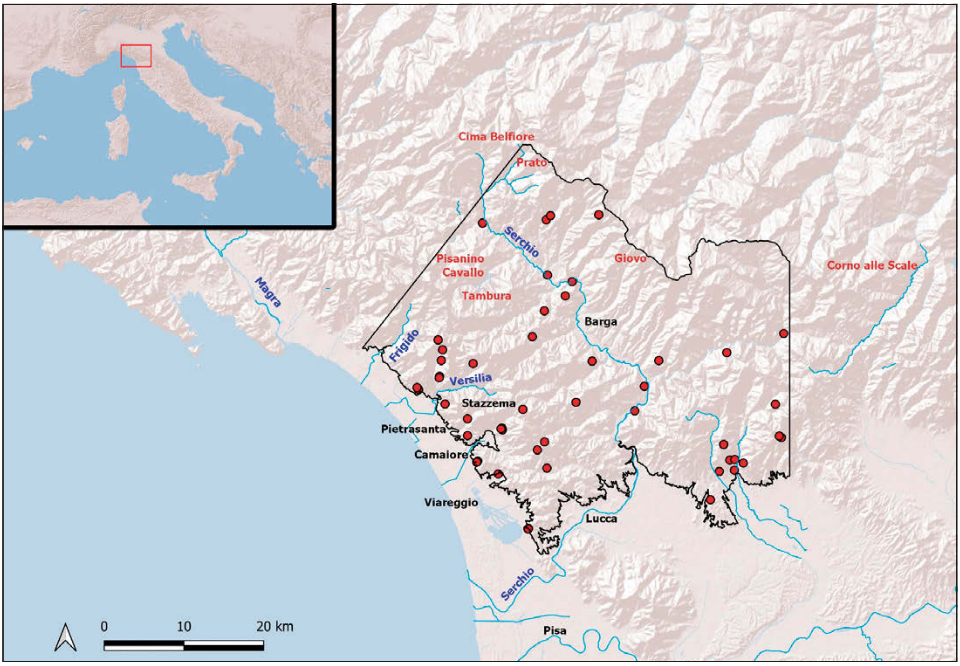

Fig. 1 – Study area and archaeological finds used in this research work.

to the E, several peaks rise above 1800 m (Cima Belfiore 1840 m, Mt. Prato 2054 m, Mt. Giovo 1991 m, Corno alle Scale 1945 m) distributed along the entire length of the watershed with the Po side. Between the two mountain ranges lies the valley of the Serchio River. The shaft of the valley up to the confluence of the Lima stream – the Serchio's main tributary – runs NW-SE, thus parallel to the coastline and the Apuan massif.

The altitude of the valley varies from 450 m a.s.l. at Piazza al Serchio – where the various branches into which the river divides (Serchio di Soraggio, di Sillano, di Gramolazzo) converge – to 220 m a.s.l. at Castelnuovo di Garfagnana, and 100 m a.s.l at Bagni di Lucca.

2.2 *Archaeological background*

The geomorphological conformation of the mountainous terrain and the dense ground cover make the internal areas difficult to access. Furthermore, the extensive abandonment of agricultural practices after World War II (Arnaez *et al*. 2011; Modica *et al*. 2017) makes ploughing rare, limiting the possibility of recognizing surface scattering. Over time, several archaeological features have been reported in these territories; however, most of these are the result of random discoveries or the activity of local enthusiasts and often limited to out-of-context pottery fragments. Studies on long-term landscape and settlement dynamics of these mountains are rare (Ciampoltrini 2003) and archaeological evidence of the Roman period, often related to seasonal activities, has often found only marginal space in the study of general settlement patterns (Giannini 2005; Ciampoltrini 2006).

Frequently, random finds are in fact the only evidence upon which a synthesis of human presence in the area can be based (Menchelli 1991, 387-388). In these cases, the partial or sketchy documentation often prevents a precise location of the finds, the lack of stratigraphic data frequently makes it impossible to specify the contexts of discovery and, in some cases, the materials found are lost without any proper study.

The non-verifiability of much of the available data entails an undeniable reliability issue of the archaeological information, leading to a sampling bias that must necessarily be considered in the analysis and interpretation processes. Nevertheless, the georeferencing of all known archaeological data for these territories provides, for the first time, an assessment of the actual density of the archaeological record in the highlands, which appears to be much higher than expected for marginal areas. These endemic uncertainties of the archaeological record led previous studies to abandon any attempts to read the settlement pattern of the mountain territory in its informative completeness and its connection with the other landscape constituents. This study stems from these reflections and aims to, at the very least, begin to fill this gap.

3. Materials and methods

3.1 *Archaeological dataset and co-variables*

The dataset derives from the collection, digitisation and systematisation of data performed as part of broader projects to analyse the settlement patterns of the cities and territories of *Pisae* and *Luca* in the Roman period. During these projects, 1026 archaeological intervention records and more than 1420 finds were catalogued for the *Pisae* territory (Campus 2022) and 427 intervention records, for a total of 1196 finds for *Luca*'s territory (Basile 2022a). An 'intervention' is every single action carried out in a specific location, from excavations and surveys to remote sensing, cores, random findings, and inspections by Superintendence. 'Finds' are classified with an increasing level of abstraction, from the traces in the field to their categorization into functional macro typologies (for a more detailed description of 'interventions' and 'finds' see Anichini, Gattiglia 2012). Given the purpose of the research, only records falling in the hilly and mountainous areas of Versilia and Garfagnana were considered in this study. Therefore, a target area was prepared using the contour line tool, selecting the portion of the territory within the isohypse of 50 m a.s.l.

The study area thus selected covers approximately 1574 km² and includes 78 finds, then reduced to 55 by using the R function remove.duplicates to find and delete points with the same coordinates (Fig. 1). The choice of independent variables is a crucial preliminary step in the creation of the model. Considering that this study focuses on the distribution of settlement in a specific mountainous environment, we deliberately decided to select as predictor for our models only those environmental variables that could have an influence on the settlement pattern, leaving out cultural variables such as toponymy or proximity to mountain passes and routes.

Among those selected are geomorphological and pedological variables. Geomorphological variables include Digital Terrain Model (*DTM*), Slope (*Sl*) Sine and Cosine of the Aspect (*sin_aspect*, *cos_aspect*), Profile Curvature (*curv*), and Tangent Curvature (*curv_tan*). Pedological variables derived from the Tuscany Region Pedological Database[1] include land use capacities such as Drainage (*Dre*), Erosion (*Eros*), Chemical Fertility (*Fert*), Landslide (*Slide*), and the percentage composition of soils: Clay (*Cla*), Sand (*San*), Silt (*Sil*), Pebbles (*Peb*), Rockiness (*Rock*), Organic Substrate (*Sostorg*). Furthermore, we also considered Distance from major waterways (*St_dist*), Total Solar Exposure, and Exposure Time measured at the summer (*Sotosu* and *Sotisu*) and winter (*Sotowi* and *Sotiwi*) solstices as possible predictors.

In a first step, the interaction between archaeological finds and variables were analysed studying the first-order effects of the point pattern. In a second phase, two regression models were constructed with selected variables using different approaches to create a predictive map of the area: a first model (Model_1a) only considers variables selected after the Point Pattern Analysis; a second (Model_2) uses variables selected and combined manually through an assessment of P-values and Akaike Information Criterion (AIC) of various models.

3.2 *Point Pattern Analysis*

Point Pattern Analysis is a method increasingly used in archaeology to provide a reliable statistical assessment of landscape and settlement dynamics (Eve, Crema 2014; Brandolini, Carrer 2020; Costanzo *et al.* 2021; Basile 2022b; Campus 2022). Point Pattern Analysis generally refers to a suite of statistical methods designed to assess the potentially complex spatial relationships that might exist among entities that can be described as points. The underlying processes behind a given point pattern are determined either by interaction with a range of exogenous influences (*first-order effects* or *induced spatial dependency*) or by intrinsic factors to the phenomena of interest (*second-order effects* or *inherent spatial dependency*) (Crema 2020, 158). In this paper, Point Pattern Analysis performed in R using the spatstat package (Baddeley *et al.* 2021) will focus on attempting to formally

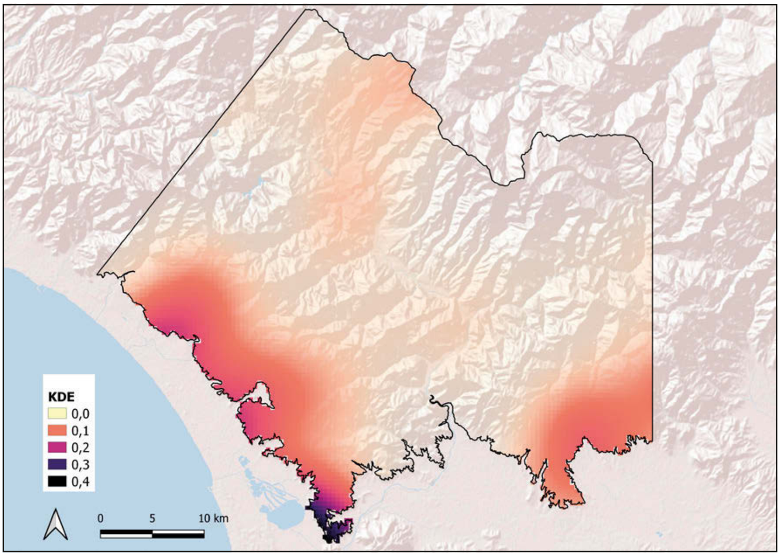

Fig. 2 – Kernel Density Estimation of the Roman period archaeological finds within the study area.

model the exogenous environmental variables that may have induced spatial dependence of the study area evidence. In other words, we will study the large-scale spatial interaction to determine whether the density of the point pattern in the study area, proportional to the intensity of the underlying process, is stationary and isotropic (Homogeneous Poisson Process - HPP) or spatially variable (Inhomogeneous Poisson Process - IPP), assessing whether an inhomogeneous model describes spatial variability more accurately than the stationary homogeneous Poisson model by fitting external covariates that might influence the distribution of spatial events (Brandolini, Carrer 2020, 5). A popular method for summarizing the first-order intensity of a point pattern is to create a density surface using Kernel Density Estimation, which computes a continuous approximation of the distribution by weighting events relative to their distance from the point from which the intensity is estimated (Conolly, Lake 2006, 175-177; Bevan 2020, 63-64).

As is clearly shown in the figure (Fig. 2), the density of points in the study area is variable and inhomogeneous, showing a greater number of points in particular areas, such as in the foothills. Following the principle of parsimony, the model was created by selecting the combination of covariates that minimises the Akaike Information Criterion (AIC) values to simplify the model without affecting performance. In this way, model 1 was created, the results of which are presented in the table (Tab. 1).

model	Covariate	Estimate	S.E.	CI 95% lo	CI 95% hi	Z test	Z-value
1	Intercept	-9,074267965	3,377345034	-15,693740000	-2,454793000	**	-2,686805000
1	DTM	-0,000901334	0,000465451	-0,001813602	0,000010934		-1,936474000
1	Cos aspect	-0,469826506	0,205848019	-0,873281200	-0,066371800	*	-2,282395000
1	Tangent Curvature	11,331528590	3,925082210	3,638509000	19,024550000	**	2,886953000
1	Slope	-0,074725602	0,023749200	-0,121273200	-0,028178030	**	-3,146447000
1	Distance from streams	0,000235373	0,000113971	0,000011993	0,000458752	*	2,065193000
1	Erosion	-0,161707472	0,109905088	-0,377117500	0,053702540		-1,471337000
1	Landslide	0,201112572	0,141027606	-0,075296460	0,477521600		1,426051000
1	Organic substrate	0,179231863	0,040165758	0,100508400	0,257955300	***	4,462305000
1	Solar total summer	-0,000881674	0,000398235	-0,001662199	-0,000101148	*	-2,213956000
1	Solar total winter	0,000351656	0,000187218	-0,000015284	0,000718596		1,878328000

Tab. 1 – Coefficients of the Point Pattern Analysis.

3.3 *Logistic Regression Modelling*

Regression models are among the most widely used approaches in archaeology to predict the relationship between the probability of encountering an archaeological site and several independent variables. Logistic regression is used to specify a binary outcome (event/non-event, present/absent, large/small, etc.): hence, logistic regression has mainly been used for the development of predictive models on the location of archaeological sites, estimating the probability that a site is present in a particular study area (Carlson 2017, 235; Nakoinz, Knitter 2018, 87-97). In our case, logistic regression was used to model the probability of encountering a frequented (event) or a non-frequented (non-event) area and to test the relationship between the presence of settlement elements and the covariables already considered for the Point Pattern Analysis.

The 55 points of our dataset were considered as 'events', assigning each of them numerical value of 1. Considering the low density of investigation in the area, it was not possible to establish points or areas that could represent 'non-events' with certainty. Therefore, 350 'non-event' points representing a process of complete spatial randomness were obtained with the QGIS Random Points tool, resulting in a ratio of 1:6 between 'events' and 'non-events' entities, as already tested in archaeology (Wachtel 2018; Li *et al*. 2022). Although we are aware of the reduced representativeness of the dataset, the event/non-event ratio, more than the total number of measures, is the most relevant parameter for structuring a robust binomial model (King, Zeng 2001).

To avoid collinearity effects in the estimation of the coefficients, the correlation between the predictors was assessed before the models were created by calculating the Pearson correlation index for each pair of variables (Fig. 3). A strong collinearity above the 0.7 threshold value (Alberti *et al*. 2018, 13) was thus established between some variables (positive: *Sotiwi-Sotowi*, *Sotiwi-Sotosu*; negative: *Sin-aspect-Sotiwi*, *Sin-aspect-Sotowi*, *Slope-Sotosu*). Even though the two variables Slope and Total Summer Solar Exposure (*Sotosu*) have a coefficient of 0.71 – just above the threshold value – we still decided

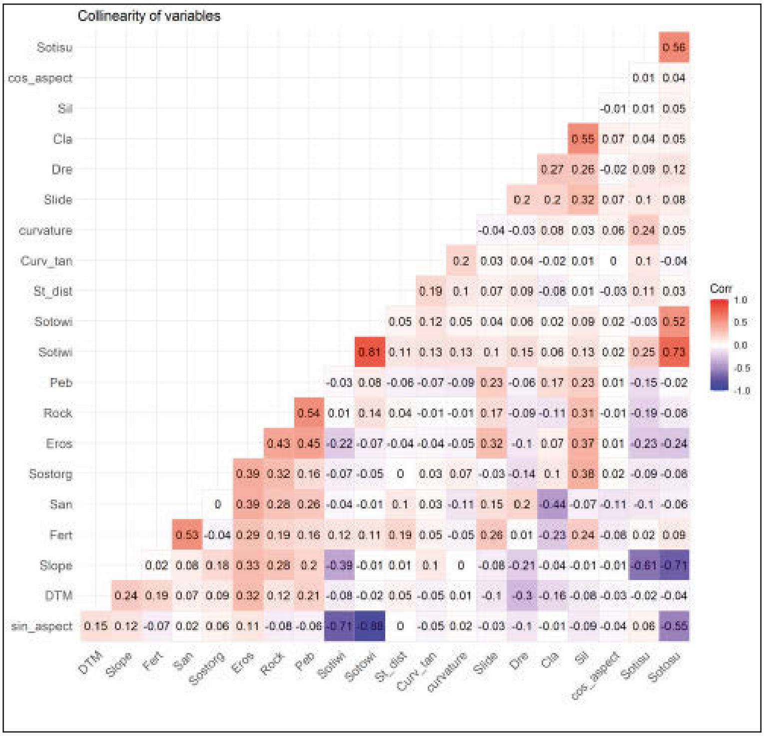

Fig. 3 – The Corrplot which shows collinearity among variables.

not to exclude them from the model. In fact, in our interpretation, these could be two of the most influential factors in establishing the settled areas. Therefore, we were interested in assessing their true impact in predicting sites.

The first model (Model 1a), created using the R glm function, only considers the variables already selected by the Point Pattern Analysis. Using the stepAIC function, a stepwise selection of these variables was performed to obtain the model with the best balance between likelihood and predictors, according to the principle of parsimony (for a similar procedure see: Basile, Carrer 2022, 71-73). The obtained model preserved 6 out of 10 variables: DTM, Slope, Cosine of Aspect, Tangent Curvature, Distance from main streams, and Organic Substrate (Tab. 2). Then, the influence of the interaction between predictors on the model was tested by multiplying two or more variables to obtain two types of information: assessing the possibility of a strong dependence between variables – in which case one of the predictors would lose its importance in the model – and assessing whether the interaction *per se* could be relevant for the model. In this way, we established that

model	Covariate	Estimate	Std. Error	Z-value	Pr(>|z|)	Z test
1a	Intercept	-0,75460	0,45830	-1,64700	0,09964	.
1a	DTM	-0,00135	0,00047	-2,86600	0,00416	**
1a	Slope	-0,02686	0,01363	-1,97100	0,04871	*
1a	Tangent Curvature	19,28000	12,86000	1,49900	0,13390	
1a	Distance from streams	-0,00014	0,00023	-0,60500	0,54498	
1a	Organic substrate	-0,08210	0,10950	-0,75000	0,45331	
1a	Cosine Aspect	-0,63890	0,23330	-2,73800	0,00618	**
1a	Dist_from_st:Org_subst	0,00013	0,00007	2,02200	0,04321	*
2	Intercept	3,19275	2,01486	1,58500	0,11306	
2	DTM	-0,00137	0,00048	-2,86500	0,00417	**
2	Slope	-0,06414	0,01900	-3,37700	0,00073	***
2	Tangent Curvature	14,54413	10,17958	1,42900	0,15308	
2	Distance from streams	0,00025	0,00014	1,86500	0,06215	.
2	Organic substrate	0,12635	0,05251	2,40600	0,01612	*
2	Cosine Aspect	-1,19060	0,35566	-3,34800	0,00082	***
2	Curvature	34,20600	15,59248	2,19400	0,02825	*
2	Landslide	0,26463	0,15306	1,72900	0,08384	.
2	Exposure Time summer	-0,36481	0,14406	-2,53200	0,01133	*
2	Org_subst:Cos_aspect	0,14131	0,06918	2,04300	0,04110	*

Tab. 2 – Coefficients of the Logistic Regression Models.

the interaction between Distance from main streams and Organic Substrate (*St_dist:Sostorg*) was particularly influential.

For comparison purposes, a second model (Model 2) was created by reconsidering all variables without the selection applied by the Point Pattern Analysis. After discarding Sin of Aspect (*sin_aspect*) and Solar Time and Total Exposure in winter (*Sotiwi, Sotowi*) due to their high collinearity, the following predictors were selected by applying the stepAIC function: DTM, Slope, Curvature, Tangent Curvature, Distance to main streams, Organic Substrate, Cosine of Aspect, Landslide, and Solar Exposure Time on the summer solstice (Tab. 2). As for Model 1a, we inspected the interaction among variables by multiplying them. In this case, the interaction between Organic Substrate and Cosine of Aspect (S*ostorg:cos_aspect*) is significant, therefore it was considered among the predictors.

As a first step in validating both models, using roc and ggroc functions (pROC package), Receiver Operator Characteristic (ROC) curves were plotted, to display the True Positive Rate (or Sensitivity) against False Positive Rate (or Specificity) (for a similar procedure see: Basile, Carrer 2022, 73). The former is the percentage of correctly predicted events, while the latter is the percentage of events incorrectly predicted as non-events. Furthermore, using the auc function, we calculated the Area Under the ROC Curve (AUC) to assess the reliability of the predictions. In a range from 0 to 1, the AUC value represents the probability that a random event is closer to 1 than a random non-event. Hence, values close to 1 indicate a high predictive capacity of the model, whereas values below 0.5 indicate low prediction reliability (Li *et al*. 2022, 8).

A chi-square test was then performed subtracting the residual deviance from the null deviance and the residual degrees of freedom from the null degrees of freedom in order to compare the response of the models with only the intercept (null deviance), against the models that include the independent

Model 1a	NO-Event	Event	Sum
NO-Event	224	126	350
Event	17	38	55
Sum	241	164	405
Model 2	NO-Event	Event	Sum
NO-Event	231	119	350
Event	14	41	55
Sum	245	160	405

Tab. 3 – Cross tables of the observed values against the fitted values of the Logistic Regression Models.

variables (residual deviance) and thus determine whether the fitted models represent an improvement over the null hypothesis that the decrease in deviance is not significantly different from zero. Subsequently, a second test was performed comparing the residual deviance and the residual degrees of freedom, with the null hypothesis that the observed values differ significantly from fitted values (Carlson 2017, 237-238).

A series of automated and manual comparisons between true positive (*tpr*) and true negative (*tpn*) prediction rates were performed to establish a threshold value, to balance as best as possible the prediction for non-events and events. Finally, a cross table (Tab. 3) was created to compare the predictions of the regression model with observed values (for a similar procedure: Campus 2022, 391-396).

The performance of the two models was finally compared, using Akaike information criterion (AIC), Schwarz's Bayesian Information Criterion (BIC), and BIC weights. The AIC is normally used to compare alternative models, generally selecting the one with the lowest AIC value (Carlson 2017, 238). The BIC is calculated as the difference between the maximum likelihood of the model and the product of the covariates for the number of observations (points), so the lower the BIC, the better the model performance. The BIC weights are used to provide a normalised estimate of the relative performance of the two models (Brandolini, Carrer 2020, 8).

3.4 *Predictive map*

Using GRASS r.mapcalc function, raster maps of the selected covariates were weighted based on their regression coefficient and combined to produce a probability map representing the logarithm of the odds for each model:

Prob = Intercept+(coef. Covar1×covar1)+(coef.Covar2×Covar2)…

The probability map was then used for both models to obtain a predictive map in which a value from 0.0 (non-event) to 1.0 (event) was assigned to each 20×20 m cell:

Pred = (exp(Prob))/(1+(exp(Prob)))

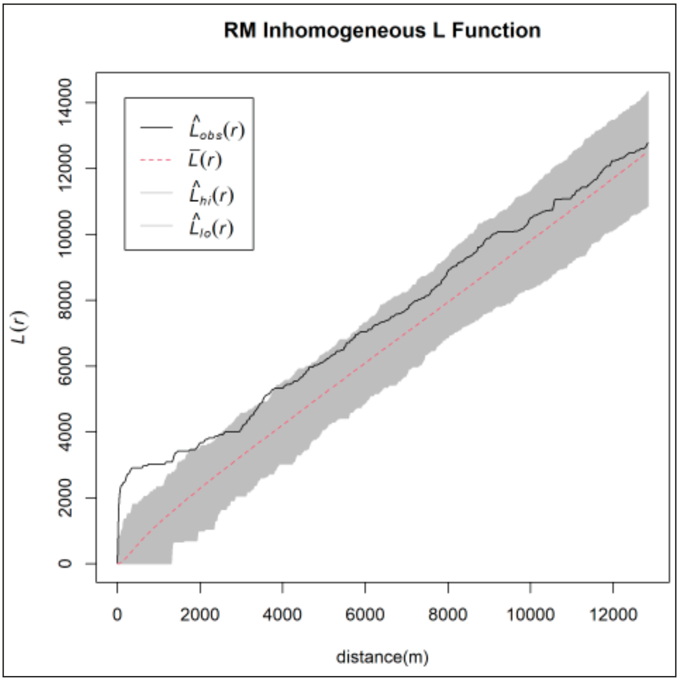

Fig. 4 – Inhomogeneous L-function.

4. Results and discussion

Exploratory analysis such as Kernel Density Estimation (Fig. 2) demonstrates the inhomogeneity of the distribution of archaeological evidence, concentrated on the foothills near the plain, where urban centres and road network were located. Point Pattern Analysis assesses the spatial dependence among points at various scales. The inhomogeneous L-function (Fig. 4) shows a significant aggregation of points – beyond the envelope interval – within 2 km, probably due to the existence of areas with a higher density of finds, resulting in clusters that do not necessarily reflect the actual settlement distribution. On a larger scale, first-order processes – namely environmental features – explain the distribution of points (Model 1). Point Pattern Analysis coefficients show a significant direct correlation with Organic substrate, Landslides and Tangent Curvature, while Distance from streams and Total Solar Exposure in winter display a weaker direct correlation. A very weak inverse correlation with DTM and Total Solar Exposure in summer and a weak one with slope and erosion are observed. In contrast, the most significant inverse correlation is with Aspect Cosine.

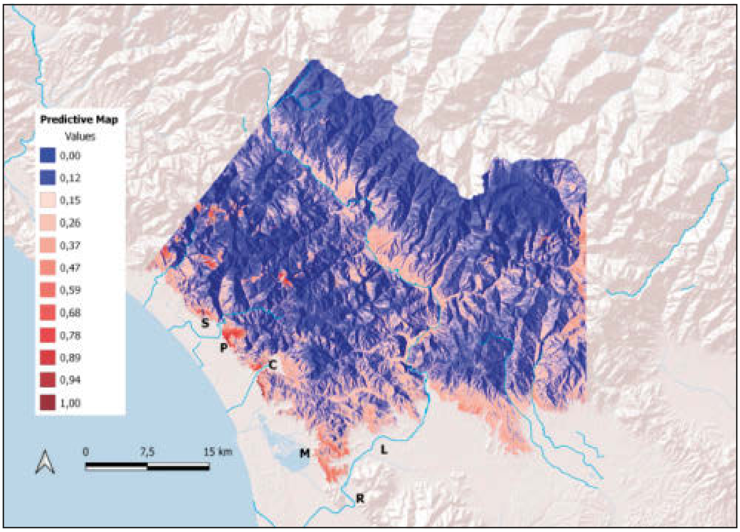

Fig. 5 – Predictive map derived from Model 1a with locations mentioned in the text: L) Lucca; R) Ripafratta; M) Massaciuccoli; C) Camaiore Valley; P) Pietrasanta; S) Strettoia.

As far as the regression models are concerned, in both models, variables with a significant inverse correlation and low P values are DTM, Slope, Cosine of Aspect (Tab. 2); while Distance from Streams and Organic Substrate have higher P values. Among the selected variables Tangent Curvature presents very high estimate coefficients, particularly affecting the predictions. Only Model 2 considers Solar Exposure Time in summer, Landslide and Curvature – the latter of which has a particularly high estimate coefficient. Furthermore, Model 1a considers the interaction between Distance from Streams and Organic Substrate (*St_dist:Sostorg*), and Model 2 the one between Organic Substrate and Cosine of Aspect (*Sostorg:cos_aspect*).

Chi-square tests prove that both models are acceptable and exhibit a significant correlation between the probability of encountering an event and the independent variables. In the first test, comparing the null deviance against the residual variance the p-values for both models are close to 0 (Model 1a: 2.174182e-08; Model 2: 5.176584e-09); similarly, the second chi-square tests return values close to 1 (Model 1a: 0.9999996; Model 2: 0.9999999). We can therefore conclude that the fitted models provide a significant improvement over the null models. For both models, the Area Under the ROC Curve (AUC) values are around 0.75 (Model 1a: 0.754961; Model 2: 0.7695584), thus showing a similar predictive capability. Threshold values were selected by comparing true positive (*tpr*) and true negative (*tpn*) prediction rates, seeking

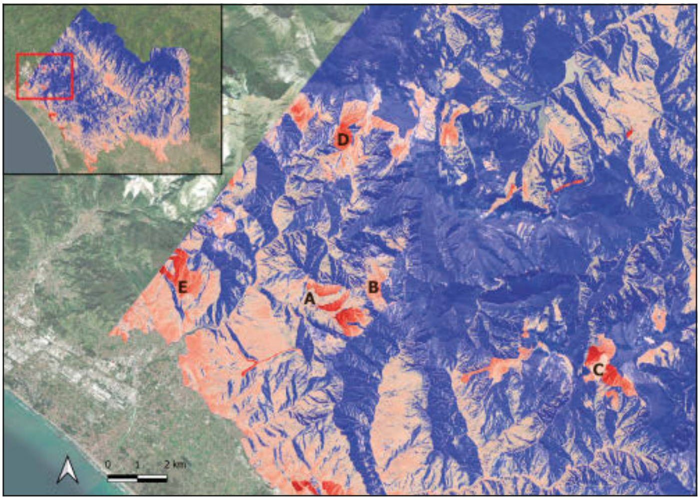

Fig. 6 – The north-western area of Model 1a predictive map with locations mentioned in the text: A) Antona; B) Mt. Altissimo; C) Foce di Mosceta; D) Vergheto; E) Mt. Brugiana.

a value that balanced the predictions between 'event' and 'non-event' (Model 1a: 0.08054071; Model 2: 0.1155059) (Tab. 3).

Finally, both models have similar AIC values (Model 1a AIC = 292.7; Model 2 AIC = 296.1) and show similar reliability and prediction capability. In fact, the BIC scores show almost identical values (Model 1a BIC score = 316.747; Model 2 BIC score = 316.092); the BIC weight is slightly higher for Model 2 (Model 1a BIC weight = 0.418; Model 2 BIC weight = 0.58); however, there are no substantial differences in reliability between models.

The application of computational models and predictive analyses in archaeology – especially when human behaviour factors are involved – should always be paired with a contextual interpretation of the multiple factors interrelated. In the case of two equally reliable models with the same predictive capacity, the choice of the best model is a crucial step that falls on the researchers who read and interpret the results (Gillings *et al.* 2020, 13). Although Model 1a has slightly lower performance, it was considered as more suitable for the construction of the predictive map. In fact, Model 1a produces a more readable and higher detailed map (Fig. 5), and the selected variables were derived from an additional Point Pattern process step that ensures the spatial dependence of the archaeological features with the environmental variables. Based on the considered variables, the predictive map confirms that the foothill area has suitable characteristics for permanent settlement, despite the study area excludes urban settlement and centuriated plain areas. The entire foothill strip tends to be above the threshold, as in the N-E of the plain of Lucca and between Ripafratta and Massaciuccoli. Values close to 1 are attested in Piana di Mommio and Santa Lucia at the Camaiore Valley entrance and the foothill to the N of Pietrasanta up to Strettoia at Lago di Porta.

Inland, the entire Serchio Valley area is at medium-low values but still above the threshold. Going up in altitude and away from main waterways, values above the threshold decrease and the non-event areas increase proportionally, especially along ridges and steepest and most exposed to the N areas. Nevertheless, event values are especially recorded in areas characterised by gentler slopes and exposed to the E-SE. Values close to 1 are located on the NE slope of Monte Altissimo at approximately 1000 m a.s.l. However, in this case, a prediction bias must be considered due to quarries that regularised slopes and mountain profiles over the centuries; therefore, predictions are probably overestimated. Plateaus with gentle slopes, such as the western side of Mt. Pania della Croce, near Foce di Mosceta, the area of Vergheto to the W of Mt. Tambura, the area of Antona, and the Mt. Brugiana at approximately 800 m a.s.l, show more reliable values toward 1 (Fig. 6).

5. Conclusion

Predictive archaeological models are tools for projecting known patterns to different, unexplored locations in the landscape (Warren, Asch 2000, 6), with the aim of generating a spatial pattern that has predictive implications for future observations and, especially in archaeology, for predicting the location of evidence not yet observed (Wheatley, Gillings 2002, 161). In this study, we aimed to explore the settlement pattern of the Versilia and Garfagnana mountains provided by previous investigations in relation to environmental variables with the purpose of integrating the archaeological framework, clarifying human-environment dynamics and past landscape use, and directing new research in the area, such as the survey campaigns currently conducted by the MAPPA Lab (Dept. of Civilisations and Forms of Knowledge, University of Pisa) within the ARAM (ARcheologie dell'Abbandono sulla Montagna di Mezzo) project. After investigating the spatial dependence of finds with environmental variables through Point Pattern Analysis, two predictive models were created. Given their equal robustness and reliability, the choice of the most fitting model to create the prediction map was then guided by the readability and interpretability of the output.

The suitable characteristics of the foothills for permanent settlement are thus confirmed; as clearly evidenced by Kernel Density Estimation, it is here, moreover, that the greatest archaeological concentration occurs, close to the plain where urban centres and the main road network were located. In any case, event values are also present in the innermost areas and at higher altitudes, especially on the gentler, E-SE-facing slopes. Usually, predictive models in archaeology rest on the assumptions that settlement choices were strongly influenced or conditioned by the characteristics of the natural environment and that these environmental factors are represented, at least indirectly, in contemporary maps (Warren, Asch 2000, 6). For these reasons, the major criticism of predictive models is environmental determinism and predictive modelling of archaeological patterns is regarded as one of the most controversial applications of computational archaeology (Wheatley, Gillings 2002, 161). Critical issues and opportunities in the archaeological modelling process have long been discussed and emphasised (Kvamme 2006) and the importance of the researcher's contextual interpretation and cross-validation of results are established.

The probably overestimated predictions at the quarry areas, due to the regularisation of slopes and mountain profiles over the centuries, are a clear example of the possible distortion due to the use of environmental factors recorded in contemporary cartography. Particularly in the mountainous area, larger and permanent settlements are often more visible and therefore often represent the only features that allow for the development of settlement location models. A predictive model that can generate a spatial pattern with predictive implications provides greater awareness of the possible extension of the settlement pattern, human-environment dynamics, and past landscape use to direct future research and field validation on lesser-known areas.

Author statement

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REFERENCES

Alberti G., Grima R., Vella N.C. 2018, *The use of Geographic Information System and 1860s cadastral data to model agricultural suitability before heavy mechanisation. A case study from Malta*, «PLOS ONE», 13, 2, e0192039 (https://doi.org/10.1371/journal.pone.0192039).

Anichini F., Fabiani F., Gattiglia G., Gualandi M.L. (eds.) 2012, *Mappa. Metodologie Applicate alla Predittività del Potenziale Archeologico*, Roma, Edizioni Nuova Cultura (https://doi.org/10.4458/0917).

Anichini F., Gattiglia G. 2012, *Urban Archaeological Information System. Riflessioni e criticità*, in Anichini *et al.* 2012, 31-41.

Arnaez J., Lasanta T., Errea M.P., Ortigosa L. 2011, *Land abandonment, landscape evolution, and soil erosion in a Spanish Mediterranean mountain region: The case of Camero Viejo*, «Land Degradation & Development», 22, 6, 537-550 (https://doi.org/10.1002/ldr.1032).

Baddeley A., Turner R., Rubak E. 2021, *Spatstat: Spatial Point Pattern Analysis, Model-Fitting, Simulation, Tests*, «R Foundation for Statistical Computing», Vienna (https://cran.r-project.org/web/packages/spatstat/spatstat.pdf).

Basile S. 2022a, *Lucca e l'*ager Lucensis *dall'età tardo repubblicana al tardoantico: le trasformazioni di una città e del suo territorio*, unpublished Doctoral Thesis, Università di Pisa (https://etd.adm.unipi.it/t/etd-06272022-165434/).

Basile S. 2022b, *The funerary landscape of late antique and early medieval Lucca through Point Pattern Analysis*, «European Journal of Post-Classical Archaeologies», 12, 87-106.

Basile S., Carrer F. 2022, *A computational modelling approach to reconstruct the fluvial system of the floodplain of Lucca in the Roman period*, «ArcheoLogica Data», 2, 63-80 (https://doi.org/10.13131/unipi/2785-0668/k5sw-3e98).

Bevan A. 2020, *Spatial point patterns and processes*, in M. Gillings, P. Hacıgüzeller, G. Lock (eds.), *Archaeological Spatial Analysis: A Methodological Guide*, Oxon, Routledge, 60-76.

Bini M., Zanchetta G., Regattieri E., Isola I., Drysdale R.N., Fabiani F., Genovesi S., Hellstrom J.C. 2020, *Hydrological changes during the Roman climatic optimum in northern Tuscany (Central Italy) as evidenced by speleothem records and archaeological data*, «Journal of Quaternary Science», 35, 6 (https://doi.org/10.1002/jqs.3224).

Brandolini F., Carrer F. 2020, Terra, Silva et Paludes. *Assessing the role of alluvial geomorphology for Late-Holocene settlement strategies (Po Plain – N Italy) through Point Pattern Analysis*, «Environmental Archaeology», 7, 5, 511-525 (https://doi.org/10.1080/14614103.2020.1740866).

Boccaletti M., Coli M., Decandia F.A., Giannini E., Lazzarotto A. 1980, *Evoluzione dell'Appennino settentrionale secondo un nuovo modello strutturale*, «Memorie della Società geologica italiana», 21, 359-373.

Carlson D.L. 2017, *Quantitative Methods in Archaeology Using R*, Cambridge, Cambridge University Press.

Campus A. 2022, *L'*ager Pisanus *tra romanizzazione e tardoantico: continuità, discontinuità e trasformazioni*, unpublished Doctoral Thesis, Università di Pisa (https://etd.adm.unipi.it/theses/available/etd-09262022-155452/).

Carmignani L., Giglia G., Kligfield R. 1978, *Structural evolution of the Apuane Alps: An example of continental margin deformation in the Northern Apennines, Italy*, «The Journal of Geology», 86, 4, 487-504.

Carrer F. 2013, *An ethnoarchaeological inductive model for predicting archaeological site location: A case-study of pastoral settlement patterns in the Val di Fiemme and Val di Sole (Trentino, Italian Alps)*, «Journal of Anthropological Archaeology», 32, 54-62.

Castaldini D., Genevois R., Panizza M., Puccinelli A., Berti M., Simoni A. 1998, *An integrated approach for analysing earthquake-induced surface effects: A case study from the Northern Apennines, Italy*, «Journal of Geodynamics», 26, 2-4, 413-431.

Ciampoltrini G. 2003, *La valle del Serchio fra I e VI secolo d.C. Aspetti della dinamica dell'insediamento*, in G. Roncaglia, A. Donati, P. Giuliano (eds.), *Appennino tra antichità e Medioevo*, Città di Castello, Petruzzi Editore, 209-223.

Ciampoltrini G. 2006, *La colonia e la montagna. Archeologia d'età augustea a Lucca e nella Valle del Serchio*, San Miniato, Tipografia Toscana.

Conolly J., Lake M. 2006, *Geographical Information Systems in Archaeology*, Cambridge, Cambridge University Press.

Costanzo S., Brandolini F., Idriss Ahmed H., Zerboni A., Manzo A. 2021, *Creating the funerary landscape of Eastern Sudan*, «PLOS ONE», 16, 7, e0253511 (https://doi.org/10.1371/journal.pone.0253511).

Crema E.R. 2020, *Non-stationarity and local spatial analysis*, in M. Gillings, P. Hacigüzeller, G. Lock (eds.), *Archaeological Spatial Analysis. A Methodological Guide*, Oxon, Routledge, 155-168.

Della Casa P. 2010, *Recherche interdisciplinaire en archéologie et écologie humaine dans la vallée centre-alpine de la Léventine, Tessin (Suisse)*, in Tzortzis, Delestre, Greck 2010a, 23-32.

Devoti S., Nisi M.F., Silenzi S. 2003, *Caratteri geologici ed evoluzione paleogeografica della pianura versiliese*, «Studi Costieri», 6, 73-89.

Eve S.J., Crema E.R. 2014, *A house with a view? Multi-model inference, visibility fields, and Point Process Analysis of a Bronze Age Settlement on Leskernick Hill (Cornwall, UK)*, «Journal of Archaeological Science», 43, 267-277 (https://doi.org/10.1016/j.jas.2013.12.019).

Giannini M. 2005, *I Romani in Versilia: dinamiche di popolamento e organizzazione del territorio*, «Orizzonti», 16, 81-91.

Gillings M., Hacigüzeller P., Lock G. 2020, *Archaeology and spatial analysis*, in M. Gillings, P. Hacigüzeller, G. Lock (eds.), *Archaeological Spatial Analysis. A Methodological Guide*, Oxon, Routledge, 1-16.

Fabiani F. 2006, "*… stratam antiquam que est per paludes et boscos…*". *Viabilità romana tra Pisa e Luni*, Pisa, Edizioni plus.

Kempf M., Weaverdyck E.J.S. 2023, *Modelling bias and environmental preferences in archaeological spatial analysis*, «Vegueta. Anuario de la Facultad de Geografia e Historia», 23, 1 (https://doi.org/10.51349/veg.2023.1.03).

King G., Zeng L. 2001, *Logistic regression in rare events data*, «Polytical Analysis», 9, 2, 137-163 (https://doi.org/10.1093/oxfordjournals.pan.a004868).

Kvamme K.L. 2006, *There and back again: Revisiting archaeological locational modeling*, in M.W. Mehrer, K.L. Wescott (eds.), *GIS and Archaeological Site Location Modeling*, New York, CRC Press, 23-55.

Li L., Li Y., Chen X., Sun D. 2022, *A prediction study on archaeological sites based on geographical variables and logistic regression. A case study of the Neolithic era and the Bronze age of Xiangyang*, «Sustainability», 14, 15675 (https://doi.org/10.3390/su142315675).

Menchelli S. 1991, *Materiali per la storia della Versilia in età romana*, «Studi Classici e Orientali», 40, 387-429.

Migliavacca M., Bandera S., Bezzi J., Casarotto A., Pisoni L. 2021, *Archeologia delle alte quote sulla montagna veneta: la campagna di ricognizione di superficie 2019 a Recoaro Terme (Vicenza)*, «Fasti On Line Documents & Research», 14, 1-30.

Mocci F., Segard M., Walsh K. 2010, *Données récentes sur l'occupation humaine dans les Alpes méridionales durant l'Antiquité*, in Tzortzis, Delestre, Greck 2010a, 309-324.

Modica G., Praticò S., Di Fazio S. 2017, *Abandonment of traditional terraced landscape: A change detection approach (a case study in Costa Viola, Calabria, Italy)*, «Land Degradation & Development», 28, 8, 2608-2622 (https://doi.org/10.1002/ldr.2824).

Nakoinz O., Knitter D. 2018, *Modelling Human Behaviour in Landscapes: Basic Concepts and Modelling Elements*, Switzerland, Springer.

Tzortzis S., Delestre X., Greck J. (eds.) 2010a, *Archéologie de la montagne européenne, Actes de la table ronde internationale de Gap (2008)*, Paris, Édition Errance.

Tzortzis S., Delestre X., Greck J. 2010b, *Avant-propos*, in Tzortzis, Delestre, Greck 2010a, 9-10.

Visentin D., Carrer F. 2017, *Evaluating Mesolithic settlement patterns in mountain environments (Dolomites, Eastern Italian Alps): The role of research biases and locational strategies*, «Archeologia e Calcolatori», 28, 1, 129-145 (https://doi.org/10.19282/AC.28.1.2017.08).

Wachtel I., Shelach-Lavi G., Garti S. 2018, *Predictive modelling for archaeological site locations: Comparing logistic regression and maximal entropy in North Israel and North-East China*, «Journal of Archaeological Science», 98, 28-36 (https://doi.org/10.1016/j.jas.2018.02.001).

Warren R.E., Asch D.L. 2000, *A predictive model of archaeological site location in the Eastern Prairie Peninsula*, in K.L. Westcott, R.J. Brandon (eds.), *Practical Applications of GIS for Archaeologists: A Predictive Modelling Kit*, London, Taylor&Francis, 5-32.

Wheatley D., Gillings M. 2002, *Spatial Technology and Archaeology. The Archaeological Applications of GIS*, London, Taylor & Francis.

ABSTRACT

Mountain archaeology has a long research tradition and in recent years the number of studies on this topic has increased considerably, shedding new light on the dynamics of mountain's communities. Versilia and Garfagnana districts (Lucca, north-western Tuscany) largely fall between the Apuan Alps and the Apennine ridge. Although these territories have never been systematically investigated, the collection of all available archaeological legacy data indicates a settlement pattern of undoubted interest for the Roman times. This paper aims at exploring the settlement pattern of these mountain territories, integrating Point Pattern Analysis and Logistic Regression to achieve a predictive map of archaeological presences and to analyse their interrelations with the environment. Analyses prove the spatial dependence of finds with geomorphological and pedological variables, but also with the distance to major watercourses and solar irradiation. Based on the considered variables, the predictive map confirms that the foothill and gentler slopes facing E-SE areas have suitable characteristics for permanent settlement. Moving towards the more inland and higher altitude territories, the non-event areas increase proportionally, especially along the ridges, and the steeper, north-facing areas. Thus, the results make it possible to integrate the archaeological framework, clarifying human-environment dynamics, and directing new studies.

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DIGITAL RESCUE OF AN ARCHAEOLOGICAL SITE AT RISK: THE PREHISTORIC VILLAGE OF PORTELLA (SICILY)

1. Introduction

Traditionally, Italian archaeological heritage has been considered the basis of the identity of the entire population of the Peninsula. Not only is this due to its intrinsic historical value, but also to its use as an instrument to raise the sense of belonging to a national community (Bencivenni, Dalla Negra, Grifoni 1987, 189-270; Troilo 2005, 74; Papi 2008, 185-186; Barbanera 2015, 52-56). These historical considerations on the intrinsic and attributed value of archaeological remains induce further reflections on their fate. In general, cultural heritage is surveyed to be studied, analysed and documented. That notwithstanding, it is often and increasingly destined to an inexorable process of deterioration caused by both anthropogenic and natural factors (Brandi 1977). Although the debate on the methods and purposes of the conservation of cultural heritage is still ongoing, one of its most recent acquisitions is the concept of planned maintenance (Laino, Massari, Pesaresi 2014; Osanna, Rinaldi 2018; Osanna, Rinaldi 2020).

The present contribution, however, aims to complement this concept with that of 'digital rescue'. Specifically, for the sites where it is impossible to carry out conservation projects due to factors such as geomorphological impediments, it is necessary to initiate procedures that limit destructive processes. These include, precisely, the aforementioned activities of 'digital rescue'. For this latter reason, the writer wants to propose a standard, expeditious and low-cost procedure to systematically and three-dimensionally survey those archaeological surfaces destined for inevitable deterioration. This process will be described in detail through a case study. A fundamental step in these projects is the experimentation with technologies that have increasingly become part of an archaeologist's daily routine. Such tools, however, must not have mere research as their purpose but must pursue the aim of archaeology, consisting of historical reconstruction and the need to hand down the remnants of the past to posterity.

2. The archaeological area of Portella

The prehistoric village of Portella is located in the eastern part of Salina, one of the seven Aeolian islands, located off the northern coast of Sicily (Fig. 1). The island, made up of six different volcanos – M. Rivi, Pizzo Capo, Pizzo Corvo, M. Fossa delle Felci, M. dei Porri e Pollara (Iacobucci *et al.* 1977; Keller 1980) – is dominated by the highest two – M. Fossa delle Felci and

Fig. 1 – Salina Island. Satellite photo (Google Earth).

M. dei Porri – which, according to some scholars, in antiquity gave the island the name of Didyme from the Greek word that means 'twins' (Bernabò Brea, Cavalier 1995, 18). The island is characterized by very steep slopes and soil that constantly slips from the upper part. The rains, over the centuries, have created deep valleys separated by ridges. The prehistoric area of Portella, ca. 240 m long, occupies one of these ridges, starting from Monte Fossa delle Felci and ending in a high cliff of 50 m.

The prehistoric village was occupied during the Middle Bronze period by people of the so-called Milazzese culture, closely related to the Thapsos culture in Sicily. In the second half of the 1950s, the village was accidentally discovered by workers who were building a road connecting the eastern part of the island to the northern one. The village is one of the most important Bronze Age sites in the archipelago, comparable to Capo Milazzese in Panarea (Bernabò Brea, Cavalier 1968, 50-163, 208-214), Capo Graziano in Filicudi (Bernabò Brea, Cavalier 1991, 191, 207-209, 214-215) and the castle area in Lipari (Bernabò Brea, Cavalier 1980, 546, 705). These villages have a lot of similarities: firstly, all of them were built in naturally defended areas, e.g., ridges or hills from where it was possible to see the sea; secondly, all these villages were destroyed in large fires during the first part of the 13th century B.C., according to Diodorus (Diod. V., 7-9), caused by people who came from Campania (Cavalier 1957, 10, 1986; Bernabò Brea, Cavalier 1991, 215). The Portella site is perfectly preserved, possibly because the area

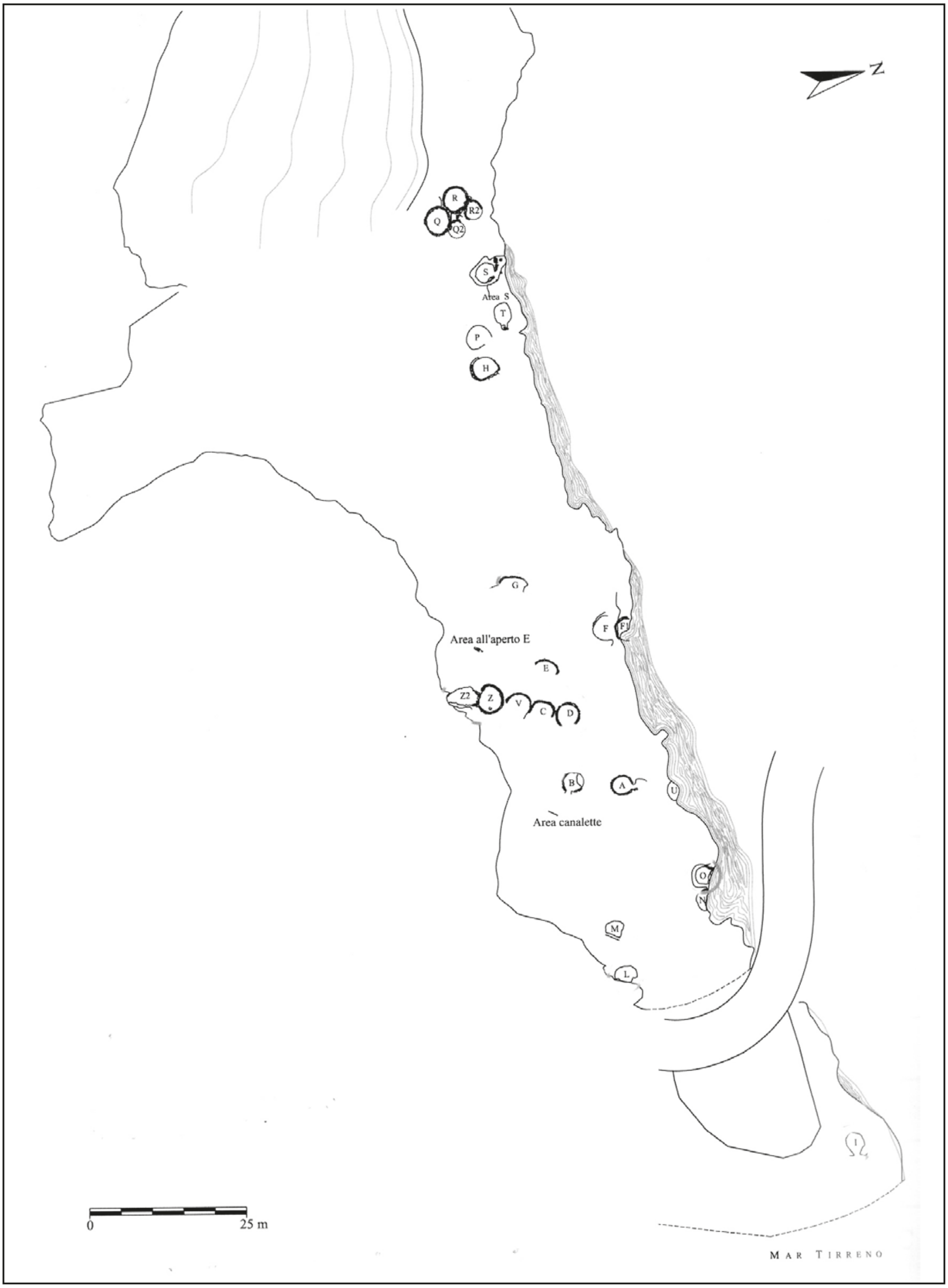

Fig. 2 – Schematic plan of the village (from Martinelli 2010).

Fig. 3 – Orthophoto of the village area.

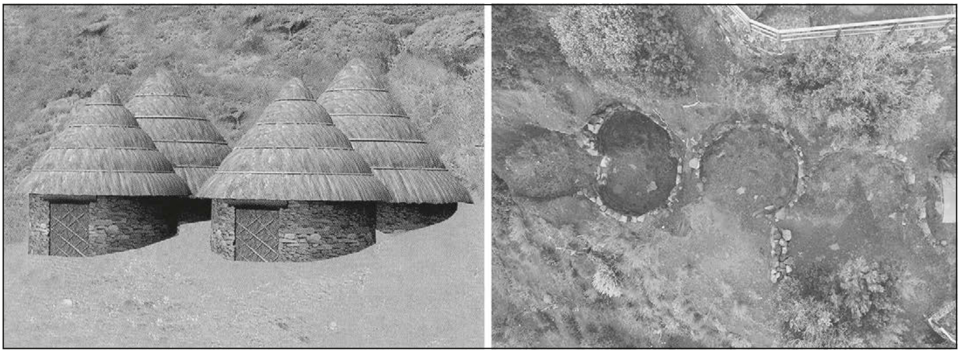

Fig. 4 – 3D reconstruction of the huts (from Martinelli 2010) and aerial photo of Z-V-C-D huts.

remained unoccupied until the 1980s and was exclusively used for the cultivation of olives. Furthermore, it was rapidly covered by landslides consisting of volcanic rocks from the higher area. These phenomena helped to preserve the Bronze Age huts and their contents.

Ten circular huts were excavated by L. Bernabò Brea and M. Cavalier in 1955 (Bernabò Brea 1955; Cavalier 1957; Bernabò Brea, Cavalier 1968, 144-180), but at the end of the campaign they were covered again to prevent their damage. In 1998, the Regione Sicilia bought the area with a POM project, and one year later another excavation (Martinelli 2001, 2005) started and continued in 2006 (Martinelli 2010). Inside these excavations, 25 circular or ellipsoidal huts with a diameter of 3-4 m were found (Figs. 2-3). These had different functions: some of them were habitations, while others were workshops. The walls were partly cut in the rock and partially constructed with two distinct types of stones: a volcanic stone with sharp edges, and one with a smooth surface, polished by the sea (Martinelli 2010, 254). The whole village was organized in small terraces, roughly the size of a hut. The huts did not necessarily occupy one level: a single building could be built on different levels, sometimes sharing walls with other dwellings (Fig. 4).

Among other features, the typology of the huts aided the defensibility of the village: their roof made up of broom could be easily mistaken with natural vegetation and the fact that they were carved in the rocks constituted an additional defense. The conic roof had to be supported by beams embedded in the walls or resting on the perimeter of the huts (Martinelli 2010). The floor consisted of beaten earth, probably to avoid humidity. The 25 huts are not single residential units: the pottery in the destruction layer helps us to understand that each dwelling had different functions. They were used as houses, workspaces, warehouses, or common areas (Martinelli 2010, 254). In the same area, some waterpipes of 30-40 cm wide to collect rainwater

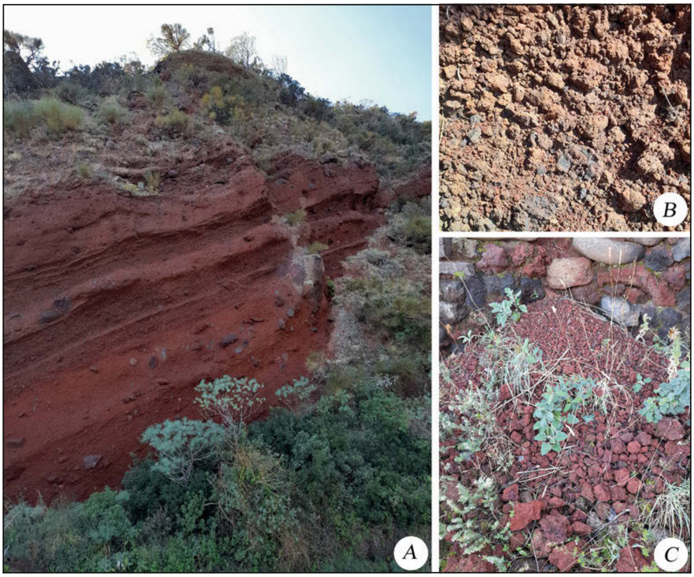

Fig. 5 – Petrography of the area: A) ridge; B) lapilli; C) eroded rocks.

were also brought to light, as were some walls that may have been used for common works (Martinelli 2010, 116-122).

Structures and open spaces were built along the northern and southern slopes of the ridge after an intensive shaping of the natural rock. Possible internal pathways must have developed on the sides of the huts through small ramps. Because of the steep slope of the ridge, the passage was likely facilitated by the presence of perishable elements such as ropes or wooden ladders. Interesting structural elements were found within the 25 structures discovered at Portella: they can be distinguished into architectural and furniture elements. The former represents the structural parts of the dwellings found, like thresholds, jambs and stairs, while the latter has a purely functional purpose for greater exploitation of the available space. This category includes hearths, closets, shelves, and *pithoi* supports. The latter were fundamental to the village: excavations have brought to light 32 of them, referable to two types and distributed both inside and outside the huts. Except for eight structures, a *pithos* was always present. This presence could be justified by the inhabitants' water supply in an area with scarce water resources. Based on the size of the huts, the open spaces and the distinct functions of the structures identified, it was possible to estimate that the village had been inhabited by about five or six households. Therefore, it was calculated that the population of the village was around 100 inhabitants (Martinelli 2010, 212).

3. Research, methods and results

The conditions of the archaeological deposit are excellent due to the constant slipping of material from the highest part of the ridge in which the site lies. This has determined the preservation of the walls and of a considerable number of artifacts inside the huts. That notwithstanding, the erosive activity negatively affects the remains (Bernabò Brea, Cavalier 1968, 163): the lateral erosion of the ridge, due to the water flow, is destroying part of the village (Fig. 5). The team that worked on the last excavation campaign recently hypothesized that around fifty percent of the protohistoric village had already been lost at the time of discovery (Martinelli 2010, 206, 254). These problems need programmatic studies and continuous monitoring of the site. For these purposes, modern photogrammetry with the use of drones is important for interpreting the material evidence and creating plans, sections, orthophotos, DEMs and 3D models. These instruments are extremely important for the monitoring, safety, restoration and enhancement of the archaeological site.

In the next sections we will present the activities and the methodology used for Portella and the making of a virtual tour that could allow the digital conservation of the buildings and an increased accessibility.

3.1 *Aerial recording and data processing*

In the last decade, drones or UAVs (Unmanned Aerial Vehicles) have become a precious instrument in the study of cultural heritage (Pecci 2021)[1]. In the archaeological field, aerial photos taken by UAVs allow archaeologists to highlight the presence, shape and dimensions of ancient remains otherwise invisible or impossible to reach. Currently, digital detection techniques are the best tool to document the archaeological evidence, in terms of accuracy, precision and detail of the data obtained. The experimentation and use of 3D digital acquisition techniques in archaeological fieldwork have now become an established practice, as confirmed by the widespread use of systems based on active sensors (range-based methods), such as laser scanners and total stations, whose methodology of acquisition and data processing is well known and standardized (Böhler, Marbs 2004).

In recent years, systems based on passive sensors (image-based methods), such as digital photogrammetry and computer vision algorithms, have become progressively optimized and are nowadays widely used in archaeology. Photogrammetry (Thompson, Gruner 1980; Mikhail, Bethel, McGlone 2001; Parisi 2012; Angelini, Gabrielli 2013, 389) and Remote Sensing (Colomina,

[1] The spread of these instruments is witnessed by the multiplication of scientific research and articles in which drones play a key role. In Italy, it is worth mentioning how these drones have achieved a prominent role in technical-scientific journals such as «Archeologia e Calcolatori» or even «Archeologia Aerea».

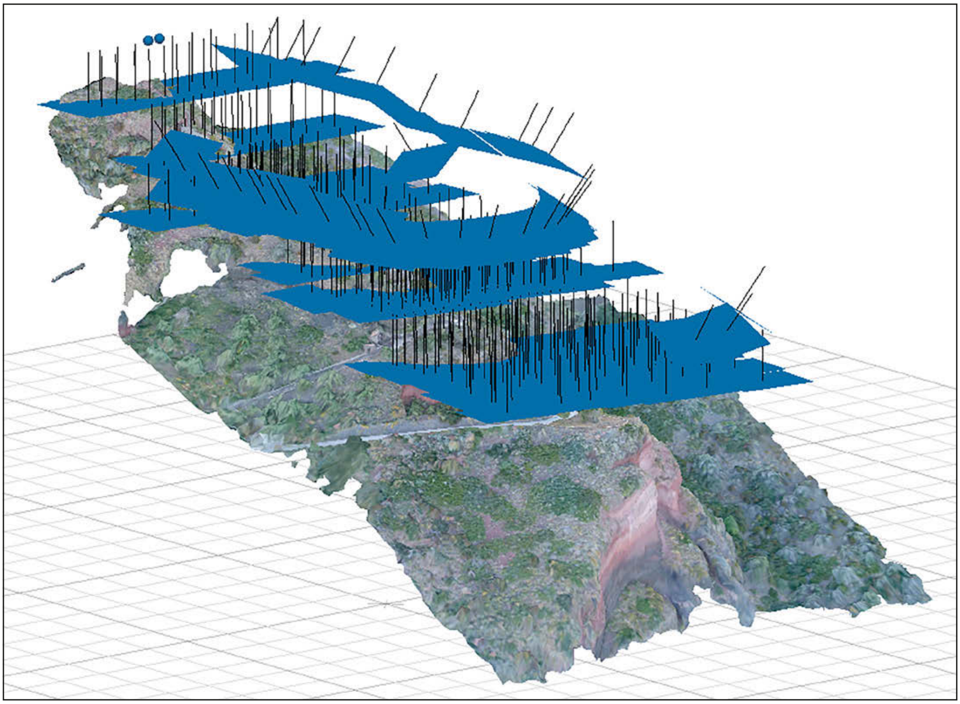

Fig. 6 – Aerial photos distribution on the ridge (Agisoft Metashape).

Molina 2014; Campana 2017) make possible the use of the Structure from Motion (Szeliski 2010; Clini *et al.* 2016) technique, helpful to generate territorial 3D models (Nex, Remondino 2014) and 3D documentation for archaeological excavations (Sfacteria 2016; Ceraudo, Guacci, Merico 2017).

To document the state of the prehistoric site of Portella (3600 m²) the work was divided into different phases, the first in the field and the second in the software environment. For the first phase, we decided to undertake a UAV survey to further preliminary steps. The first and most important one is the flight planning. In general, the operator creates a flight configuration using a dedicated application, in which it is possible to set variables like the speed of the drone, the flight altitude, the angle of sight of the camera and the shooting mode. It is necessary to perform a pre-flight to check for the correctness of the plan designed. Once all the parameters are verified, it is possible to begin the survey. During the flight, the UAVs proceeds automatically following the loaded settings but the operator in any case has to remain in the vicinity to deal with unexpected events, which can be related to various factors (wind, vegetation, presence of infrastructure, loss of satellite signal, etc.).

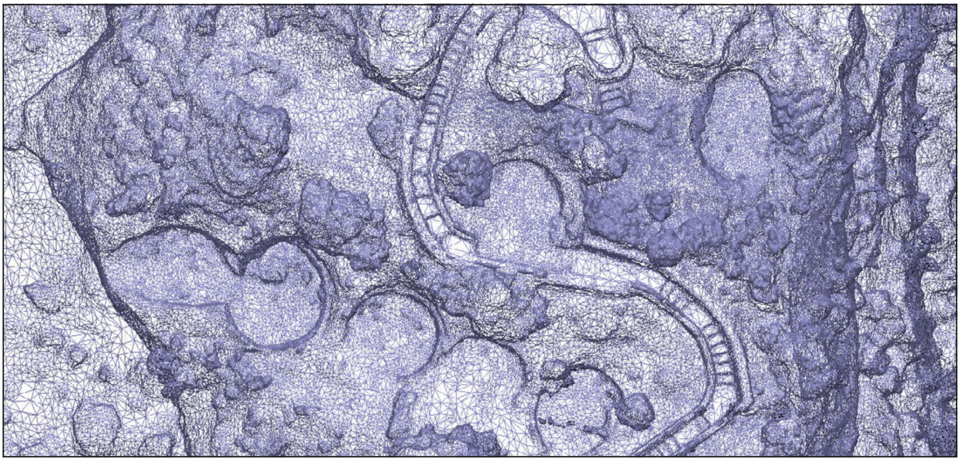

Fig. 7 – Mesh reconstruction in wireframe mode (Agisoft Metashape).

It is advisable to fly under optimal conditions of wind and light-shadow, and it is essential that the area to be surveyed is mostly clear of tall grass that could obscure the archaeological remains. For this project a DJI Phantom 4 Pro drone[2] was used, its trajectory following parallel lines from N to S. We took 420 zenithal and oblique photos at a variable height of 5-20 m from the ground, sloping from E to W. To obtain a total coverage of the area, all the photos have an overlap range from 50 to 70% (Fig. 6). In the second phase of the work, the photos were processed in Agisoft Metashape software. Normally, the workflow involves the following steps: camera calibration, images acquisition and pre-processing, tie points extraction, images orientation, point cloud generation, generation of the mesh, and texturing (Remondino, El-Hakim 2006; Barazzetti, Remondino, Scaioni 2010; Russo, Remondino 2012). At the stage of image orientation, the algorithm detects up to 40,000 tie points per photo, leading to the creation of a sparse point cloud. Once the point cloud is turned from sparse into dense, we can create the geometric structured model (mesh), of which it is possible to set some parameters, such as the quality of the model and the total number of triangles.

The last operation involves the generation of photorealistic texture, which allows projecting onto the shaded surface a blend of the images taken to create the 3D object. The resulting model must be scaled and oriented, by setting a known distance or entering known coordinates both absolute and

[2] Quadricopter weighing 1388 g, with 4 brushless motors equipped with compass, altimeter, GPS, and a range of approximately 20 minutes. Equipped with a camera, mounted on a 3-axis gimbal stabiliser, 20 Megapixel, 8.8 mm/24 mm lens, f/2.8-f/11 and autofocus.

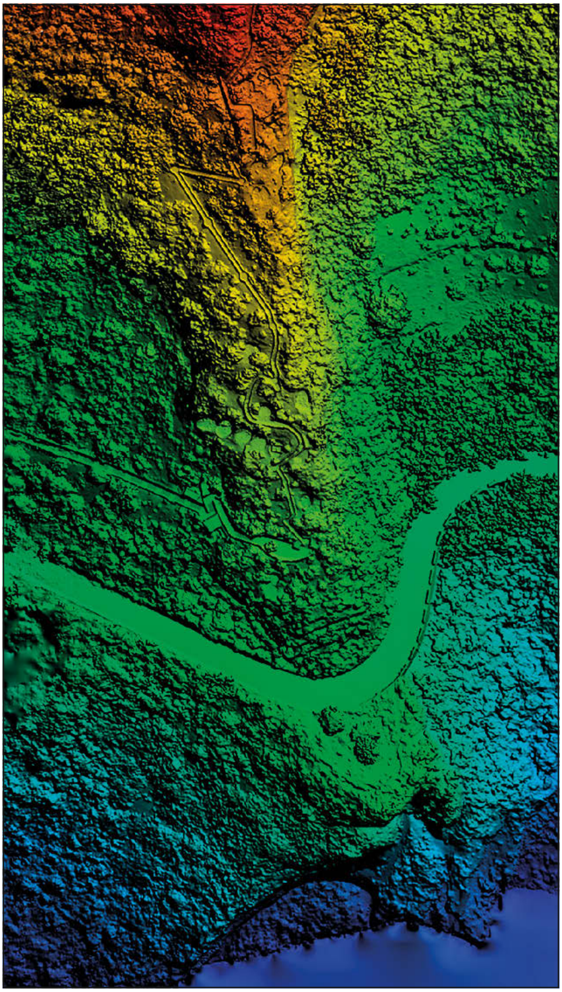

Fig. 8 – DEM of the village area.

relative, using ground control points (GCPs) appropriately distributed on the survey area and measured with a total station or a GNSS. In our case it was possible to create a dense cloud of 359,567 points, a mesh of 2,652,048 faces (Fig. 7) and a 3D model, for which 5:20, 3:10 and 3:40 hours of processing in the software environment were respectively required. The project, scaled with metric references on the ground, was georeferenced for greater precision, thanks to some GPS points deriving from a previous topographical survey conducted during the archaeological mission of 2008-2009.

Fig. 9 – Northern face of the ridge. Wind erosion has created a hole.

3.2 *Results*

Two important outputs extrapolated from the 3D model were an orthophoto (9.63 mm/pixel) (Fig. 3) and a DEM (Fig. 8) (1.93 cm/pixel) (Zoni 2017, 219-221). The overlap between the new orthophoto and the previous topographical documentation confirms that we have lost part of the surface on the northern and southern sides of the ridge, especially nearby the huts O, Z2 and F1. The flow of water and the wind are eroding the northern part of the ridge: that is why we see an accumulation of stones (red lapilli) at the end of the slope, under the place where hut O is located. The natural activities also affect an area where a very worrying grotto is sited (Fig. 9). This could potentially lead to the partial collapse of the prehistoric village, especially in the area where huts F and F1 are located. The orthophoto shows another problem, too: plants and shrubs are growing within the archaeological evidence, impeding a complete view of the village and contributing to run-off risk. Hut U is particularly affected by these problems: this dwelling is no longer visible and is partly lost. It should be noted as well that the presence of shrubs also negatively affects the realization of DTM based on aereophotogrammetry. For this problem there is, at the moment, no other solution than taking constant care of the site and its spontaneous vegetation, which can encourage the construction of more accurate and precise models.

The possibility to carefully record the development of the erosive activity, once a year or more frequently, is obviously followed by the opportunity to understand this process, in terms of measurements, distances and timing of the erosion (Taccola, Olivito 2019). The orthophoto can have a second function, consisting of creating a new survey of the area. Compared with the previous product made through traditional techniques, such as a manual survey on points taken with the total station, the survey through UAVs will certainly present a greater degree of detail and accuracy.

3.3 *A virtual tour for the site*

In the last years, virtual reality became one of the most useful techniques to enhance and enjoy cultural heritage, especially in relation to archaeological sites with accessibility issues (Arnold *et al.* 2001; Barbieri *et al.* 2017; Pecci 2018, 1678-1679). There are several reasons for creating a virtual tour: the first one is the opportunity to expand the audience by offering a visit to an archaeological site to all those people unable to go there in person for various reasons. Among them, we also find the need to connect cultural sites with an audience that needs new forms of communication. For digital natives, experiencing a combination of education and entertainment is indeed significant and could be pursued by exploiting immersive technologies and educational gaming (Scatà, Bertolini, Hohenstein 2021, 40). Virtual reality also allows us to live different experiences, e.g., reconstructing a specific place in 3D. Finally, the focus of our contribution, that is the creation of Virtual Tours (and attached 3D reconstructions), can also be considered an effective resource to preserve and communicate fragile, damaged or endangered historical sites and monuments (Grün *et al.* 2004; Fernàndez-Palacios *et al.* 2017; Mah *et al.* 2018). A fitting example in this regard may be considered the *Rebuilt Palmyra?* exhibition held in Constance in 2017, in which together with some 3D prints, virtual reality led the visitor to the city of Palmyra before its destruction (Skowronsky *et al.* 2018).

For the village of Portella a virtual tour was made with two different functions: firstly, to take a picture of the state of preservation of the monument and secondly, to ensure greater fruition. The archaeological site is located on a high ridge and the visit is possible only by means of long stairways. This made the place hardly accessible to people with physical disabilities or reduced mobility, such as the elderly. The virtual navigation could make it possible to move on the ridge and to explore the huts or the whole village with the help of a special menu provided with a navigation bar and arrow to move in different directions. The virtual tour was built up in two phases: the first was carried out in the field and consisted of shooting 360° photos with the Insta360 One X2 camera[3].

A compatible smartphone (Samsung A21s) was used in conjunction with this camera, which allows users to preview the shot, change settings (such as quality, resolution, ISO, white balance, exposure, etc.), select the shooting mode, view and transfer content on the camera or device via the Insta360

[3] Aperture F2.0. Equivalent to 35 mm focal length 7.2 mm. Photo Resolution 360°: 6080×3040 (2:1) Pan: 4320×1440 (3:1).

Fig. 10 – 360° photo taken with Insta360 One X2.

Fig. 11 – Virtual tour. Information provided by the panels and arrow keys (Marzipano Tool).

Studio app. The Insta360 One X, consisting of two 180-degree lenses, generates two fisheye images of the surroundings; the smartphone, via the app, also takes care of stitching the photographs and videos generated by the camera.

The stitching procedure via the app is a very simple process: once the photograph is captured, the user can access the gallery, select the images contained in the camera and start the saving process on the smartphone. In the end, the result will be an equirectangular photo. The second phase was the creation of a tour with Marzipano Tool, a web service free of charge (https://www.marzipano.net/tool). The first process has provided thirty-three spherical photos starting from the entrance of the site, continuing up the terraces, and arriving at every single hut. All the pictures were taken during sunset hours, helping us to have a good range of colours and no overexposed photos (Fig. 10). In software environments, the spherical photos were processed to remove hypothetical errors of stitching or unwanted elements.

The new visit itinerary to follow has been ideally programmed with Marzipano Tool. Each space/area generated from the images uses spherical projection, which creates a virtual environment that can be viewed through specific interactions, such as Drag to (rotating the view by dragging), or Move to (performing a continuous rotation toward the chosen direction and the rotation ends when the interaction is stopped).

For navigation between environments, the 360° tour uses hotspots. It is possible to move inside the scene with the same arrows provided to change the view (Fig. 11). In the case of hotspots used for navigation, the corresponding area to be reached will be associated in the parameters of the action. The result of the connection between the various environments via hotspots is the creation of a map in the workspace, showing all the connections between the various environments. For each hut or archaeological evidence, it is possible to activate specific hotspots with different digital contents (texts, photos and videos) that have a dual function: to prevent the digital visitor from missing some real details, and to enrich the educational and cultural offer.

The file, consisting of a group of JavaScript, CSS and HTML codes, could be improved with the help of programmers: it could be possible to change the layout or to have more details. The work, conducted with the approval of the Archaeological Museum Luigi Bernabò Brea at Lipari, could be shared with the public through the website of the Museum or loaded on hardware (e.g., a screen) in the rooms of the Museum, in which the main materials from the archaeological site are on display.

4. Conclusions

The archaeological site of Portella, situated in S. Marina Salina (ME), could be considered one of the most endangered monuments in Italy. Natural phenomena, misguided political choices, and the lack of maintenance (just once a year before summer) have damaged the archaeological site. One of the aims of this paper was to show how a periodic monitoring with drones could be the base of a maintenance plan. One similar process was carried out on the Punta Stilo sanctuary at Caulonia (RC) between 2012 and 2014. Part of the archaeological surface is now lost because of a storm surge (Taccola, Olivito 2019, 100-102, figs. 9-10). Although this event was more violent than the slow erosion of the archaeological surface in Portella, in the long run, the results of this process may be comparable with what we saw in Punta Stilo, especially for the portion of the site endangered by the action of the wind (Fig. 10). More specifically, a yearly elaboration of orthophotomosaics would make it possible to understand the conditions of the village, to calculate its vulnerability and to comprehend the potential risk of erosion and landslides. This work could also help the local institutions to compile an adequate program for making the slopes safe.

The potentialities of the virtual tour respond to different purposes. Firstly, the tour will also permit digital openings of the site to new users; thanks to this, problems of accessibility, such as the considerable altimetric difference between the entrance and the upper part of the village, would be easily overcome. Secondly, it can ensure the digital preservation of the site. Even in the worst possible scenario, the destruction of the site, archaeological evidence could still be enjoyed with digital devices (PC, smartphones, and tablets) or with 3D viewers for an immersive experience. Consequently, in the event of serious endangering, this digital preservation is surely a remarkable opportunity to make the site accessible for a longer period. That notwithstanding, we should be aware that we are not yet capable of producing digital data that last forever: for this reason, while IT research goes on to make data supports more and more durable, we propose in this article a periodical monitoring[4]. By producing new datasets in a determined time, we can avoid their irreparable loss or damage. Even though this type of intervention is periodical, it is extremely low cost and not at all time-consuming, as the elaboration time for the process shows (see above, § 3.1).

Finally, we should consider whether to apply this procedure to other Italian sites (or cases) with various preservation and fruition problems. For example, another possible application of these processes can involve the possibility to make virtually accessible those structures which are under restoration. Moreover, when mass tourism or the lack of adequate security conditions for people and archaeological remnants become a problem for the preservation of archaeological evidence, we should consider if a possible solution to these problems could be avoiding a 'physical' fruition of the sites (or parts of them) in favor of a virtual one (just to mention the most resounding case, Osanna 2020, 351-384). This should not be interpreted as a restriction but as a possible safeguarding instrument to be applied in extreme circumstances.

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[4] Nowadays, this instance is becoming more urgent in various scientific fields: just to give an idea about how significant these issues are, I refer to the commitment of the University of Helsinki to preserve the datasets of its researchers (https://www.helsinki.fi/en/helsinki-university-library/library-researchers/helda-digital-repository).

REFERENCES

Angelini A., Gabrielli R. 2013, *Laser scanning e photo scanning. Tecniche di rilevamento per la documentazione 3D di beni architettonici ed archeologici*, «Archeologia e Calcolatori», 24, 379-394 (http://www.archcalc.cnr.it/indice/PDF24/21_Angelini_Gabrielli.pdf).

Arnold D., Chalmers A., Fellner D. (eds.) 2001, *VAST '01: Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage (Glyfada 2001)*, New York, ACM Press.

Barazzetti L., Remondino F., Scaioni M. 2010, *Automation in 3D reconstruction: Results on different kinds of close range blocks*, «International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences», 38, 5, 55-61.

Barbanera M. 2015, *Storia dell'archeologia classica in Italia: dal 1764 ai giorni nostri*, Roma, Laterza.

Barbieri L., Bruno F., Muzzupappa M. 2017, *Virtual museum system evaluation through user studies*, «Journal of Cultural Heritage», 26, 101-108 (https://doi.org/10.1016/j.culher.2017.02.005).

Bencivenni M., Dalla Negra R., Grifoni P. 1987, *Monumenti e Istituzioni*, 1, Firenze, Alinea.

Bernabò Brea L. 1955, *Salina (Dydime)*, «Rivista di Scienze Preistoriche», 10.

Bernabò Brea L., Cavalier M. 1968, *Meligunìs Lipára III. Stazioni preistoriche delle isole Panarea, Salina e Stromboli*, Palermo, S.F. Flaccovio.

Bernabò Brea L., Cavalier M. 1980, *Meligunìs Lipára IV. L'Acropoli di Lipari nella Preistoria*, Palermo, S.F. Flaccovio.

Bernabò Brea L., Cavalier M. 1991, *Meligunìs Lipára VI. Filicudi. Insediamenti dell'età del Bronzo*, Palermo, Accademia di Scienze, Lettere e Arti.

Bernabò Brea L., Cavalier M. 1995, *Meligunìs Lipára VIII. Salina: ricerche archeologiche (1989-1993)*, Palermo, Accademia di Scienze, Lettere e Arti.

Böhler W., Marbs A. 2004, *3D scanning and photogrammetry for heritage recording: A comparison*, in *Geoinformatics 2004. Geospatial Information Research: Bridging the Pacific and Atlantic. Proceedings of 12th International Conference on Geoinformatics (Gävle 2004)*, Gävle, Gävle University Press, 291-298.

Brandi C. 1977, *Teoria del restauro*, Torino, Einaudi.

Campana S. 2017, *Drones in Archaeology. State-of-the-art and future perspectives*, «Archaeological Prospection», 24, 5 (https://doi.org//10.1002/arp.1569).

Cavalier M. 1957, *Salina. A prehistoric village in the Aeolian Islands*, «Antiquity», 31, 9-14.

Cavalier M. 1986, *Salina nella preistoria e nell'età greca e romana*, in L.S. Herzog Von Absburg, *Die Liparischen Inseln, II. Salina* (Riproduzione litografica dell'originale con trad. a cura di P. Paino), Lipari, Edinixe, 77-81.

Cavallaro C., Maccarone E. 1982, *Isole Eolie*, Genova, Sagep Editore.

Ceraudo G., Guacci P., Merico A. 2017, *The use of UAV technology in topographical research: Some case studies from Central and Southern Italy*, «SCIRES-IT-SCIentific RESearch and Information Technology», 7, 1, 29-38.

Clini P., Frapiccini N., Mengoni M., Nespeca R., Ruggeri L. 2016, *SfM technique and focus stacking for digital documentation of archaeological artifacts*, «ISPRS Archives», 41-B5, 229-236.

Colomina I., Molina P. 2014, *Unmanned aerial systems for photogrammetry and remote sensing: A review*, «ISPRS. Journal of Photogrammetry and Remote Sensing», 92, 79-97.

Fernàndez-Palacios B.J., Morabito D., Remondino F. 2017, *Access to complex reality-based 3D models using virtual reality solutions*, «Journal of Cultural Heritage», 23, 40-48 (https://doi.org/10.1016/j.culher.2016.09.003).

Fiorentino G. 2005, *Analisi archeobotanica*, in Martinelli 2005, 263-278.

Fiorentino G., Colaianni G., Grasso A.M., Stellati A. 2010, *Analisi archeobotanica*, in Martinelli 2010, 235-241.

Grün A., Remondino F., Zhang L. 2004, *Photogrammetric reconstruction of the Great Buddha of Bamiyan, Afghanistan*, «The Photogrammetric Record», 19, 107, 177-199 (https://doi.org/10.1111/j.0031-868X.2004.00278.x).

Iacobucci F., Incoronato A., Rapolla A., Scarascia S. 1977, *Basament structural trends in the volcanic islands of Vulcano, Lipari and Salina (Eolian Islands, Southern Tyrrhenian Sea) computed by aereo-magnetic and gravimetric data*, «Bollettino di Geofisica Teorica e Applicata», 20, 49-61.

Keller J. 1980, *The island of Salina*, «Rendiconti della Società Italiana di Mineralogia e Petrologia», 36, 489-524.

Laino A., Massari A., Pesaresi P. 2014, *La manutenzione programmata ad Ercolano. Obiettivi e complessità di una macchina di cura continua e sostenibile*, in *Quale sostenibilità per il restauro? Estratti del 30° Convegno di Studi Scienza e beni culturali (Bressanone 2014)*, Venezia Marghera, Edizioni Arcadia Ricerche, 505-515.

Mah O.B.P., Yan Y., Tan J.S.Y., Tan Y.X., Tay G.Q.Y., Chiam D.J., Wang Y.C., Dean K., Feng C.C. 2018, *Generating a virtual tour for the preservation of the (in)tangible cultural heritage of Tampines Chinese Temple in Singapore*, «Journal of Cultural Heritage», 39, 202-211 (https://doi.org/10.1016/j.culher.2019.04.004).

Martinelli M.C. 2001, *Portella (Santa Marina Salina, Isole Eolie, prov. Messina)*, «Rivista di Scienze Preistoriche», Notiziario, 51, 527-528.

Martinelli M.C. (ed.) 2005, *Il villaggio dell'età del Bronzo medio di Portella a Salina nelle isole Eolie,* Firenze, Istituto Italiano di Preistoria e Protostoria.

Martinelli M.C. (ed.) 2010, *Archeologia delle isole Eolie. Il villaggio dell'età del Bronzo medio di Portella a Salina. Ricerche 2006 e 2008*, Milano, Rebus.

Martinelli M.C., Fiorentino G. 2008, *The fires of Aeolian villages at the end of the Middle Bronze Age: The case of Portella site in the Salina Island (ME - Italy)*, in G. Fiorentino, D. Magri (eds.), *Charcoal from the Past. Cultural and Paleoenvironmental Implications, Proceedings of the third International Meeting of Antracology (Cavallino, Lecce, 2004)*, BAR International Series 1807, Oxford, Archaeopress, 177-181.

Mikhail E.M., Bethel J.S., McGlone J.C. 2001, *Introduction to Modern Photogrammetry*, New York, Wiley&Sons.

Nex F., Remondino F. 2009, *UAV for 3D mapping applications: A review*, «Applied Geomatics», 6, 1-28.

Osanna M. 2020, *Pompei: il tempo ritrovato. Le nuove scoperte*, Milano, Rizzoli.

Osanna M., Rinaldi E. 2018, *La manutenzione programmata*, in M. Osanna, R. Picone (eds.), *Restaurando Pompei. Riflessioni a margine del Grande Progetto*, «Studi e Ricerche del Parco Archeologico di Pompei», 38, 135-156.

Osanna M., Rinaldi E. 2020, *Il sistema programmato di prevenzione e manutenzione di Pompei: dalla sperimentazione al metodo*, in A. Russo, I. Della Giovampaola (eds.), *Atti del Convegno Internazionale di Studi Monitoraggio e manutenzione nelle aree archeologiche. Cambiamenti climatici, dissesto idrogeologico, degrado chimico-ambientale (Roma 2019)*, Roma, L'Erma di Bretschneider, 35-43.

Papi F. 2008, *Cultura e tutela nell'Italia unita, 1865-1902*, Perugia, Tau.

Parisi L. 2012, *Fotogrammetria e/o fotomodellazione*, in A. Casale (ed.), *Geometria descrittiva e rappresentazione digitale. Memoria e innovazione*, Roma, Kappa, 55-62.

Pecci A. 2018, *La Realtà Virtuale (Virtual Reality) per la conservazione e la fruizione virtuale del patrimonio immateriale*, in V.D. Porcari (ed.), *La conservazione del patrimonio artistico, architettonico, archeologico e paesaggistico*, *Atti del XIV Congresso internazionale di riabilitazione del patrimonio (Matera 2018)*, Napoli, Luciano Editore, 1676-1685.

Pecci A. 2021, *Introduzione all'utilizzo dei droni in archeologia*, Roma, Arbor Sapientiae Editore.

Racheli G. 1998, *Eolie: natura, storia, arte e turismo*, Milano, Mursia.

Remondino F., El-Hakim S. 2006, *Image-based 3D modelling: A review*, «The Photogrammetric Record», 21, 115, 269-291.

Remondino F., Fraser C. 2006, *Digital camera calibration methods: Considerations and comparisons*, «International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences», 36, 5, 266-272.

Russo M., Remondino F. 2012, *Laser Scanning e fotogrammetria: strumenti e metodi di rilievo tridimensionali per l'archeologia*, in G.P. Brogiolo, D.E. Angelucci, A. Colecchia, F. Remondino (eds.), *Teoria e metodi della ricerca sul paesaggio d'altura*, Mantova, SAP, 141-170.

Scatà L., Bertolini M., Hohenstein U.T. 2021, *Virtual tour e fotogrammetria 3D applicati al Museo universitario di Paleontologia e Preistoria P. Leonardi*, in F. Barbagli, E. Cioppi, E. Falchetti, A.M. Miglietta, G. Pinna (eds.), *I musei scientifici italiani nel 2020*, Museologia Scientifica Memorie, 39-45 (https://www.anms.it/upload/rivistefiles/1754e70229c038cca5a0a07c2b24df1b.pdf).

Sfacteria M. 2016, *Fotomodellazione 3D e rilievo speditivo di scavo: l'esperienza del Philosophiana Project*, «Archeologia e Calcolatori», 27, 271-289 (https://doi.org/10.19282/AC.27.2016.14).

Skowronsky M., Wieland J., Borowski M., Fink D., Grösch el C., Klinkhammer D., Reiterer H. 2018, *Blended Museum: The interactive exhibition Rebuild Palmyra*, in S. Abdennadher, F. Alt (eds.), *MUM 2018, Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia (Cairo 2018)*, New York, Association for Computing Machinery, 529-535 (https://doi.org/10.1145/3282894.3289746).

Szeliski R. 2010, *Computer Vision: Algorithms, Applications*, London, Springer.

Taccola E., Olivito R. 2019, *Il dato oltre l'immagine aerea: il rilievo 3D da APR per la documentazione, l'analisi e il monitoraggio in archeologia*, «Archeologia Aerea», 13, 96-104.

Thompson M., Gruner H. 1980, *Foundations of Photogrammetry, Manual of Photogrammetry*, Falls Church, Virginia, American Society of Photogrammetry.

Troilo S. 2005, *La patria e la memoria. Tutela e patrimonio culturale dell'Italia unita*, Milano, Mondadori Electa.

Zoni F. 2017, *L'uso della tecnologia DEM nella documentazione archeologica. Alcune applicazioni in casi di contesto stratigrafico e nello studio dell'edilizia storica*, «Archeologia e Calcolatori», 28, 1, 219-238 (https://doi.org/10.19282/AC.28.1.2017.13).

ABSTRACT

The prehistoric village of Portella (Salina, Eolian Islands, ME), occupied during the Middle Bronze period, was discovered by chance in the 1950s and excavated in three different phases, from the moment of discovery until 2008. The site is well preserved because, after partial destruction, it was rapidly covered by landslides of volcanic rock. That notwithstanding, the erosive activity had negative effects, too: the lateral erosion of the ridge is destroying part of the village; possibly a portion was already collapsed at the time of discovery. We can consider this erosion an unstoppable process that needs programmatic, continuous monitoring of the site. In the article, we will discuss how it is possible to make one 'screenshot' of the monument's status with the help of new technologies, specifically, photogrammetry through UAVs. To enhance fruition, a virtual tour of the site was also created. This allows people with physical disabilities or reduced mobility to access, though virtually, the site. In conclusion, other possible areas of application of this low-cost and expeditious methodology are suggested, in particular inaccessible or overcrowded sites.

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ARCHAEOBIM ED EXTENDED MATRIX. ANALISI E POTENZIALITÀ DI DUE PROCESSI PER L'ELABORAZIONE DI MODELLI INFORMATIVI

1. Introduzione

Sin dalle loro prime applicazioni, i processi di ricostruzione virtuale di contesti archeologici sono stati accolti dalla comunità scientifica in maniera disomogenea (Garagnani *et al.* 2021, 77-83). Se da un lato è stata ampiamente rimarcata la potenzialità di questi mezzi espressivi in quanto strumenti di sintesi conoscitiva e divulgativa di dati complessi (Yu Hook 2016, 684), d'altro canto ne è stata parimenti sottolineata la potenziale ambiguità dei prodotti e la fisiologica difficoltà nel rintracciare le fonti e i processi logico-deduttivi che hanno portato alla loro elaborazione (Demetrescu 2018). In quest'ottica, la possibilità di generare modelli virtuali informativi si sta configurando a tutti gli effetti come una delle nuove linee di sviluppo della Virtual Archaeology (VA); disciplina che, dopo anni di dibattito sulla sua legittimità come strumento di visualizzazione, ha trovato una sua sistemazione metodologica nelle carte di Londra (London Charter 2009) e soprattutto di Siviglia (Seville Charter 2012).

L'opportunità di configurare i modelli virtuali come veri e propri contenitori di informazioni porta dunque alla possibilità di costruire dei prodotti che trascendono la sola rappresentazione visuale, diventando parimenti degli efficaci contenitori dei processi logico-deduttivi necessari alla loro realizzazione (paradati). Nel corso di questo articolo verranno prese in esame due di queste metodologie, l'ArchaeoBIM e l'Extended Matrix. Questi due processi, messi a punto in anni recenti, rispondono entrambi alla necessità di trasformare i modelli virtuali in contenitori di informazioni, associando alle istanze che li costituiscono una serie di metadati e paradati, richiamabili e interrogabili in fase di fruizione e studio. Entrambi i processi si inseriscono pienamente nella cornice metodologica della VA, configurandosi come implementazioni rispetto ai più "tradizionali" processi di modellazione e visualizzazione, in pieno accordo ai principi 3 e 4 della Carta di Londra e ai principi 4, 5 e 7 di quella di Siviglia.

Nella prima parte di questo contributo si proporrà dunque un confronto sistematico tra questi due processi, considerando sia gli obiettivi che ne orientano l'applicazione che i risultati ottenibili da entrambi, mentre nella seconda parte del contributo verrà invece proposto un protocollo di integrazione tra i due. L'obiettivo è quello di individuare una metodologia efficace per descrivere al meglio la proposta ricostruttiva di un contesto archeologico non più preservato e caratterizzato dalla presenza di molteplici fasi di vita. Lo spunto per un confronto strutturato tra i due metodi nasce dalla recente applicazione di entrambi al medesimo contesto di Marzabotto, la Casa 1 della *Regio* IV, *Insula* 2 (R.IV, 2).

Il sito di Marzabotto è stato negli anni al centro di numerosi progetti di VA, diretti e coordinati dalla cattedra di Etruscologia dell'Università di Bologna, volti a migliorare la comprensione delle strutture archeologiche per il pubblico non specialista, colmando l'imponente divario che intercorre tra la percezione delle evidenze archeologiche sul campo (conservate perlopiù solo a livello di fondazioni) e il ruolo architettonico degli edifici in antico, comprensibile solo al termine di un lungo e filologico lavoro di studio e analisi archeologica (Gaucci *et al.* 2015).

A partire dai primi esperimenti della fine degli anni '90 (Sassatelli, Taglioni 2000) e dei primi anni 2000 (Beltrami 2010, specificatamente incentrato sulla Casa 1), i più importanti risultati sono stati ottenuti nel corso del progetto FIR 2013: *KAINUA. Restituire, percepire, divulgare l'assente. Tecnologie transmediali per la città etrusca di Marzabotto* che ha permesso di approdare ad una filologica restituzione dell'abitato (Garagnani 2017; Gaucci 2017; Govi 2017; Gruška *et al.* 2017; Muzzarelli, Franzoia 2017) e di trasformare il sito di Marzabotto in un vero e proprio laboratorio di VA (Garagnani *et al.* 2017, 15). In tempi recenti il sito è stato poi tra i protagonisti del progetto e-Archeo (https://e-archeo.it/), nel corso del quale alcuni contesti, tra cui la Casa 1, sono stati selezionati sulla base della loro importanza sul piano storico e della loro potenzialità narrativa e ricostruiti mediante il processo dell'Extended Matrix.

2. Extended Matrix e ArchaeoBIM: processi a confronto

Prima di entrare nel dettaglio del confronto tra le due metodologie, rispetto agli obiettivi e ai risultati ottenibili con entrambe, sembra lecito richiamare brevemente i principi fondamentali dell'Extended Matrix e dell'ArchaeoBIM, rimandando all'ampia bibliografia disponibile per i necessari approfondimenti metodologici di entrambi.

2.1 *Extended Matrix*

L'Extended Matrix (EM) è un linguaggio descrittivo semantico basato sulla teoria dei grafi, e più specificatamente sull'Harris Matrix (Harris 1979; Harris *et al.* 1993), quest'ultimo ampiamente utilizzato in ambito archeologico come tecnica di rappresentazione della stratificazione dei depositi archeologici e degli alzati degli edifici. Nell'EM (Demetrescu 2015, 2018; Demetrescu, Fanini 2017; Demetrescu, Ferdani 2021), alle Unità Stratigrafiche (US) che descrivono la successione di azioni di un determinato

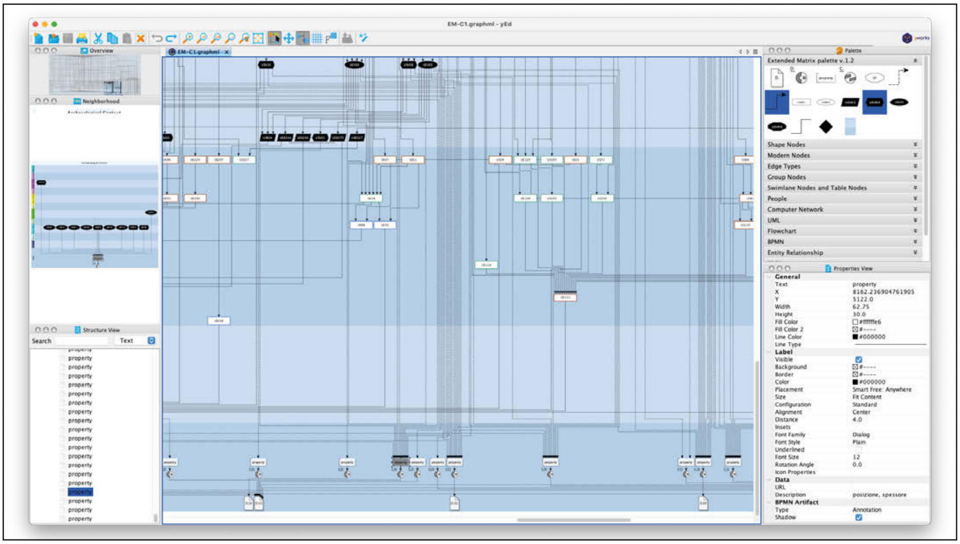

Fig. 1 – Particolare dell'EM realizzato per il caso studio della Casa 1 della R.IV, 2 di Marzabotto.

contesto vengono associate delle Unità Stratigrafiche Virtuali (USV), ovvero le ipotesi ricostruttive riguardanti una o più specifiche US ora non più esistenti a causa di una interruzione nella storia del contesto archeologico, come ad esempio la distruzione del tetto o il crollo delle pareti (Demetrescu 2015, 47). Il processo logico-deduttivo che porta alla creazione di una specifica USV è documentabile attraverso diversi nodi, volti ad inserire all'interno del grafo le fonti consultate (document node), le informazioni desumibili dalle stesse (extractor node) e le proprietà che quella combinazione di informazioni ha prodotto (property node) (Demetrescu, Fanini 2017).

Il risultato finale di questo processo è un unico grafo che descrive lo stato del deposito archeologico e la sua (o le sue) ipotesi ricostruttive, organizzando i dati secondo una sintassi visuale standardizzata (Fig. 1). Il grafo viene poi importato in un software di modellazione poligonale, dove le informazioni e i paradati relativi alle singole US e USV vengono associati alle geometrie. Il risultato finale è quindi un source-based model del singolo contesto, in cui le fonti e i processi messi a punto per la ricostruzione vengono associati alle geometrie corrispondenti, fornendone una annotazione semantica.

Il processo, come descritto nella letteratura più recente (Demetrescu, Ferdani 2021) si compone di cinque step, a partire dalla collezione dei dati (che prevede la loro sistemazione all'interno di una tabella delle fonti), procedendo per l'analisi stratigrafica, l'annotazione dei resti archeologici e la loro visualizzazione in ambiente 3D grazie a modelli proxy. A questi vengono poi aggiunte le ipotesi ricostruttive, sviluppate sia in forma di modelli proxy, che di nodi all'interno dell'EM. Si genera così un modello collaborativo, che può essere messo a disposizione per ulteriori modifiche e per la validazione, ed il cui aspetto cooperativo si sostanzia nella possibilità di far operare in modo asincrono molteplici utenti sul modello e sul grafo.

Gli step successivi prevedono poi la realizzazione di un modello di dettaglio, che ricalca la struttura sviluppata sulla base dei proxy, ma con una miglior risoluzione grafica e un livello di dettaglio (LoD) superiore, e la pubblicazione di tutti i dati usati per la ricostruzione assieme al modello stesso. Il processo di modellazione segue in senso inverso quello descrittivo del grafo, partendo dall'esistente (generalmente le fondazioni e i muri), passando per l'anastilosi virtuale degli elementi conservati (definiti "special finds") fino ad arrivare agli elementi strutturali oggi inesistenti (coperture).

Va infine sottolineato che, nonostante l'EM sia stato sviluppato per essere svincolato da specifici software, esiste ad oggi un ottimo ecosistema di programmi e plug-in che permettono di gestire l'intero flusso di lavoro mediante software freeware e open source usati per gestire ed elaborare il database grafico (yEd), connettere il grafo con il modello 3D (Blender con l'add-on EMtools: Demetrescu 2022) e visualizzarne la ricostruzione (EMviq).

2.2 *ArchaeoBIM*

L'ArchaeoBIM è una metodologia di ricostruzione sviluppata per la restituzione di edifici parzialmente perduti, o di cui si conservano solo poche tracce, e incentrata su processi di modellazione delle informazioni di costruzione espressi per mezzo di modelli BIM (Garagnani *et al.* 2021). Il Building Information Modeling risulta ampiamente utilizzato nella moderna scienza delle costruzioni come metodo di progettazione e ottimizzazione della pianificazione, in quanto tutti i dati del progetto di un edificio vengono raccolti, combinati e collegati digitalmente. Rispetto ad altri processi che utilizzano i modelli virtuali come mezzo descrittivo, il BIM si caratterizza per l'utilizzo di una rigorosa semantica architettonica, in cui i vari componenti che descrivono un edificio vengono generati parametricamente attraverso una coerente sintassi strutturale. Gli elementi strutturali sono gerarchicamente organizzati in famiglie (per es., muri, travi, tetti, porte, finestre, etc.) e suddivisi in tipi, per i quali è possibile definire puntualmente misure, proprietà, componenti e rapporti (Fig. 2).

Nella declinazione archeologica dell'ArchaeoBIM, il flusso di lavoro non differisce molto da quello applicato all'architettura moderna, per il quale il BIM è stato creato. Concentrandosi su contesti conservati perlopiù a livello di fondazioni, il processo prevede la "ri-progettazione" dell'edificio antico a partire dall'analisi tecnica delle fonti archeologiche disponibili per il contesto. Il processo di modellazione segue dunque quello di progettazione (antica e

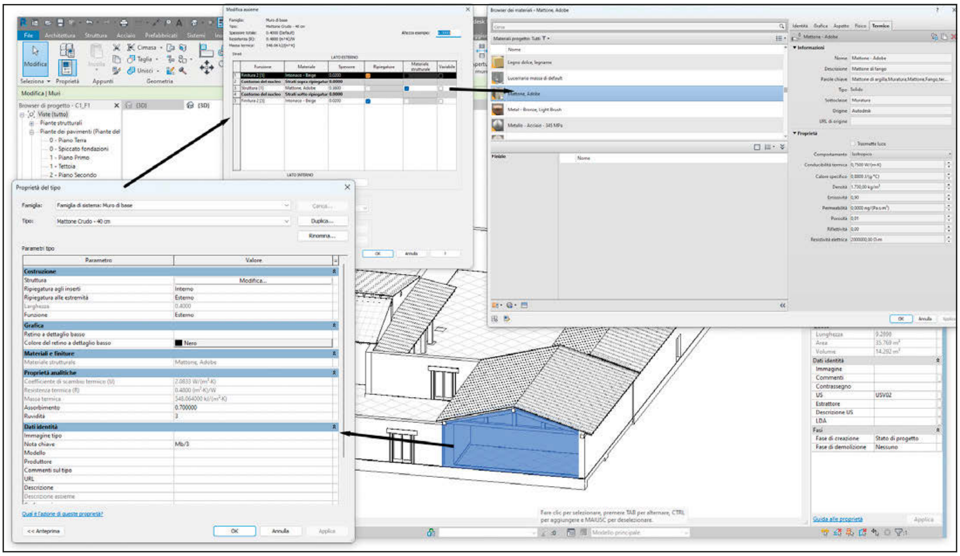

Fig. 2 – Particolare del processo di definizione delle proprietà di un muro in mattoni crudi nella ricostruzione BIM della Casa 1 della R.IV, 2. In evidenza i pannelli di definizione del tipo, della stratigrafia e dei materiali utilizzati.

moderna; cfr. Giuliani 2006, 53-60) e prevede primariamente la definizione degli elementi architettonici (cioè muri, pavimenti, tetti, etc.), che daranno la forma all'edificio, per arrivare poi a quelli strutturali (fondazioni, pilastri, travi, etc.), vincolati ai primi con funzione di supporto. Lo scopo è infatti quello di arrivare alla plausibile restituzione di un edificio antico in una o più fasi del suo alzato. Il processo nasce primariamente con l'intento di fornire una validazione di credibilità architettonica all'edificio ricostruito (Gaucci 2017, 101), facilitandone la revisione a tutti gli step del processo, dalla riflessione iniziale sulle tecniche e i materiali costruttivi, attraverso la loro messa in opera virtuale, fino alla simulazione finale rispetto a stimoli esterni: fisici, termici, meteorici, luminosi (Garagnani *et al.* 2016a, 2016b; Gaucci 2017).

Un rilevante aspetto dei modelli BIM è la loro natura come insieme di oggetti parametrici contenenti informazioni, di fatto dei database 3D con i dati e i paradati dei loro stessi elementi costituenti; in quanto raggruppamenti di dati, questi possono essere implementati e arricchiti fino a generare dei veri e propri modelli federati (Garagnani *et al.* 2021, 152-154). La rappresentazione geometrica diventa così una dei molti possibili attributi che descrivono feature che caratterizzano un edificio non più esistente. Anche nel metodo ArchaeoBIM l'aspetto collaborativo gioca un ruolo di primaria inportanza, soprattutto grazie alla possibilità di esportare i dati in schemi standardizzati, quali IFC, fondamentali per rendere i singoli modelli interoperabili tra molteplici software (cfr. *infra*), favorendo pertanto il confronto multidisciplinare (Gerbino *et al.* 2021).

2.3 *Considerazioni preliminari*

Da queste considerazioni preliminari sui due metodi emergono alcuni spunti di confronto. *In primis* va sottolineato come entrambi i processi condividano il medesimo obiettivo finale, cioè quello di approdare alla descrizione dell'ipotesi ricostruttiva di un contesto archeologico mediante un modello virtuale. In entrambi i casi, inoltre, il modello deve necessariamente configurarsi come un contenitore di informazioni, raggruppando al suo interno dati, paradati e metadati che possano essere messi a disposizione dell'utenza finale e/o che possano essere utilizzati per generare ulteriori forme di visualizzazione informativa basata sugli stessi. Per entrambi, inoltre, la base dati risulta in gran parte sovrapponibile e consiste almeno in un rilievo del contesto, in un'analisi tecnica dei resti architettonici rinvenuti (Giuliani 2006, 26-27) e in una riflessione strutturata sulla sequenza di fasi dello stesso. Per il processo EM questa si sostanzia nell'Harris Matrix, fondamentale punto di partenza per la redazione dell'EM.

Il livello di dettaglio dei reperti o lo stato di conservazione delle strutture di per sé non sembrano inficiare il risultato ottenibile con entrambi i metodi, come testimoniano i risultati delle diverse esperienze di modellazione del contesto della Casa 1 della R.IV,2 (Mancuso 2023b). Entrambi i processi sembrano poi parimenti utilizzabili per la realizzazione di una ricostruzione multifase, pur con alcune differenze sul piano dei risultati, dettate primariamente dal tipo di software utilizzato per la generazione dei modelli (cfr. *infra*). Rispetto ai risultati ottenibili, una riflessione comparativa può essere strutturata su due fattori principali: il processo di generazione dell'elemento informativo e il suo prodotto finale. Nel caso dell'EM, l'aspetto informativo si concentra maggiormente sul processo logico-deduttivo e descrittivo dei paradati del modello, per cui si propone una strutturazione espositiva formale, standardizzata ed efficace all'interno del grafo descrittivo del contesto (Demetrescu, Fanini 2017). Nell'ArchaeoBIM, invece, questo stesso aspetto si incentra sulle proprietà architettoniche e strutturali dell'elemento ricostruito e soprattutto sul ruolo svolto all'interno del progetto, imponendo meno vincoli per quanto riguarda la mappatura e l'uso delle fonti utilizzate nella ricostruzione o il livello di affidabilità della porzione ricostruita (Garagnani *et al.* 2021, 120-122).

Questo differente approccio all'aspetto informativo della ricostruzione sembra sostanziarsi in una maggior devozione al dato archeologico nel primo metodo e ad un più spiccato interesse a quello architettonico-strutturale nel secondo. Così, per la generazione del medesimo elemento, ad esempio

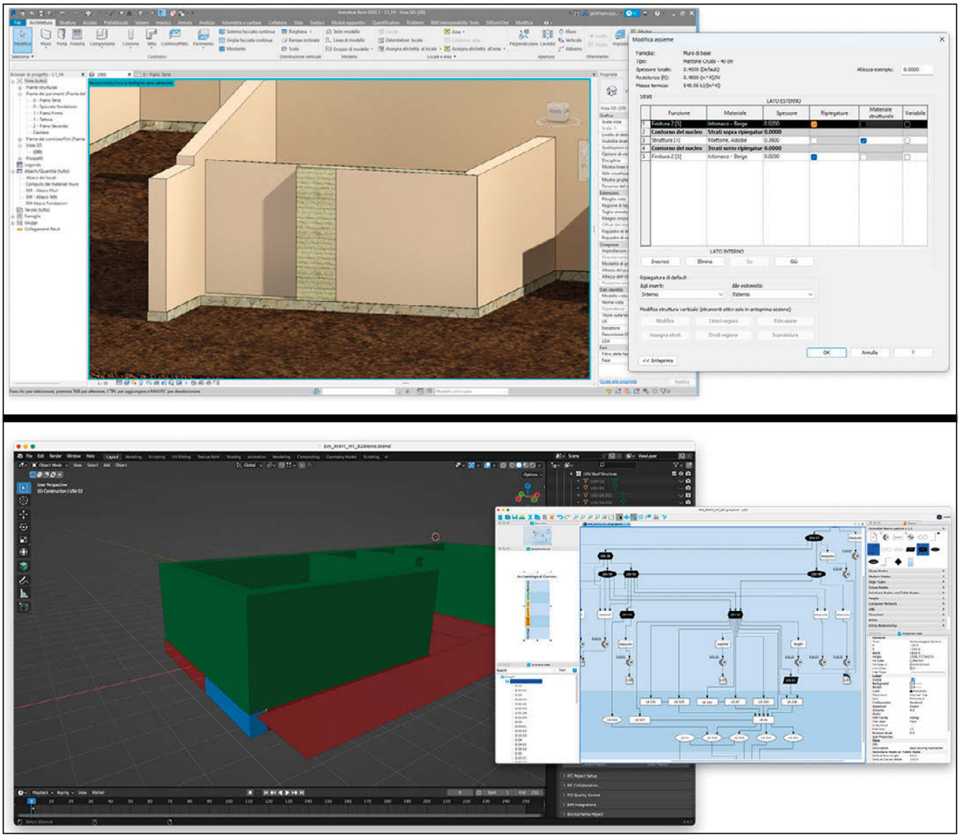

Fig. 3 – Differente approccio alla descrizione della stratigrafia muraria tra i processi BIM (in alto) ed EM (in basso), con particolare attenzione alla componente geometrica della ricostruzione.

un muro, il processo ArchaeoBIM rivolge primariamente l'attenzione sulla definizione puntuale dei suoi aspetti architettonici: i materiali usati, la loro tecnica di messa in opera, la stratigrafia, fino ad arrivare alla precisa definizione delle caratteristiche termico-fisiche di quell'elemento. Questa attenzione viene richiesta dal processo BIM stesso e trova uno spazio espositivo ottimale all'interno del software, configurato appositamente per la gestione di questo tipo di informazioni. Per contro il processo EM incentra il processo espositivo dei paradati dell'elemento (altezza, larghezza, materiale, etc.) sul percorso logico-deduttivo che ha portato alla loro definizione, imponendo di espletarne chiaramente il processo nel corso della definizione dell'EM. Alcune informazioni, dunque, quali la stratigrafia muraria, per cui pure è configurabile uno spazio descrittivo idoneo all'interno del grafo, non sembrano però trovare

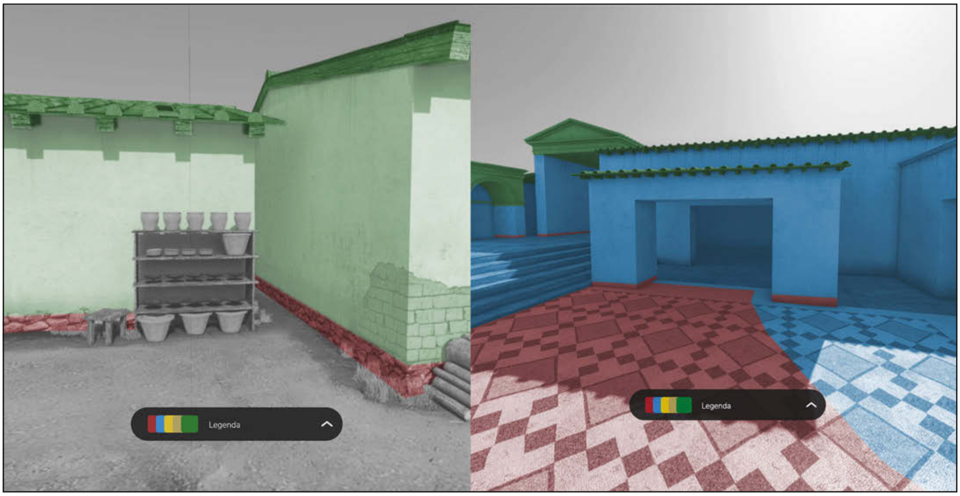

Fig. 4 – Render ricostruttivo realizzato con EM della Casa 1 (a sinistra) e del Santuario di Escluapio di Nora (a destra). In rosso le US, in verde le USV e in blu il restauro virtuale a partire da evidenze fisiche (da e-Archeo 2022; render: Katatexilux).

un altrettanto efficace corrispettivo nella fase di modellazione, in un software non costruito per la gestione di dati specificatamente architettonici, ma più generalmente poligonali (Fig. 3).

Un ulteriore e forte elemento di distinzione tra i due processi riguarda il tipo di prodotto che viene generato. Il flusso di lavoro dell'EM porta infatti alla realizzazione di almeno due modelli poligonali (proxy e di dettaglio) che si differenziano per il diverso LoD delle geometrie, ma che rimangono fondamentalmente due ricostruzioni distinte all'interno di una o più scene virtuali connesse ad un database di informazioni (Demetrescu, Ferdani 2021). Questi, pur diventando efficaci contenitori del processo intellettuale percorso per generarli e descritto dall'EM, risultano però meno idonei a produrre nuove informazioni che trascendano l'aspetto più schiettamente visuale. Nel prodotto finale risulta dunque sacrificato l'aspetto di sperimentazione che si può condurre sul modello (simulazioni fluido-dinamiche, illuminazione, etc.), fondamentalmente limitata ai soli aspetti visuali (Demetrescu 2018, 103-106). Certamente, la possibilità di generare proceduralmente forme di visualizzazione basate sul livello di affidabilità dei dati a disposizione risulta uno dei risultati più interessanti del processo ricostruttivo, che produce così un output standardizzabile e facilmente confrontabile. Ad ogni tipo di nodo usato per la descrizione del contesto il sistema assegna infatti automaticamente un codice cromatico che differenzia le USM (rosso), il loro completamento (blu), gli elementi di anastilosi virtuale (giallo scuro), il loro restauro virtuale

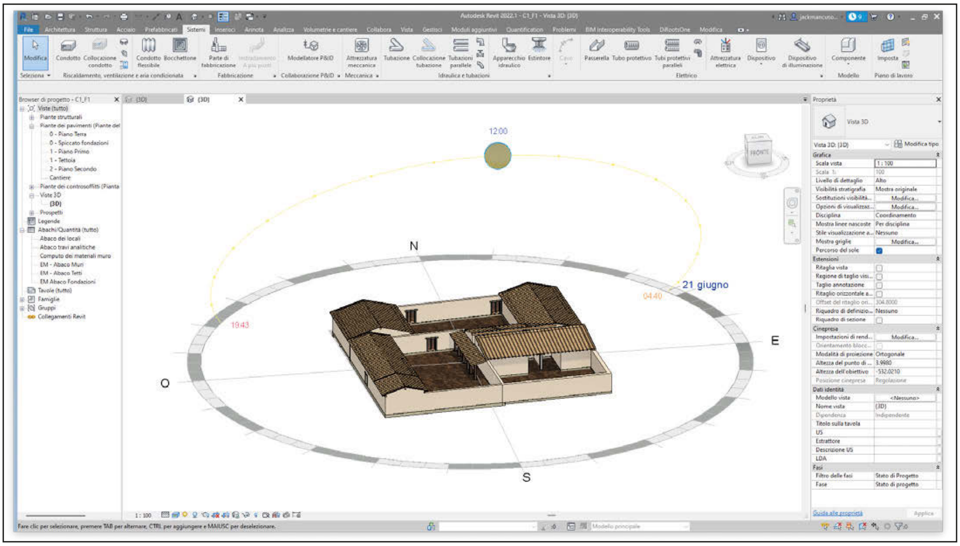

Fig. 5 – Modello ricostruttivo BIM della prima fase della Casa 1.

(giallo chiaro) e gli elementi architettonici il cui posizionamento viene fatto sulla base dell'analisi tecnica dell'edificio (verde) (Demetrescu, Ferdani 2021, con ampia selezione di casi studio).

Questa procedura, per quanto molto efficace in contesti ad elevata complessità architettonica e ricchi di elementi di cui fare anastilosi (colonne, capitelli, fregi decorati), tende tuttavia ad appiattire visivamente l'esito del processo ricostruttivo nelle situazioni in cui questo viene svolto primariamente su materiali architettonici scarsamente conservati o quasi interamente perduti, le cui proprietà (presenza, posizione, messa in opera) sono dedotte quasi interamente sulla base dell'analisi tecnica. Il problema si osserva ad esempio nella caratterizzazione dei modelli di contesti scarsamente preservati sul piano archeologico, dove, ad eccezione delle fondazioni, la quasi totalità delle strutture ricostruite viene descritta da USV e appare pertanto di colore verde (Fig. 4). Ne risulta pertanto un fisiologico appiattimento nella definizione visuale del livello di affidabilità, senza una apparente distinzione tra gli elementi con una credibilità ricostruttiva maggiore (muri, elementi di copertura del tetto, per cui si dispone generalmente di chiare tracce archeologiche) e quelli più incerti (porte, finestre, intelaiature lignee, tutte costituite da materiali deperibili).

Per contro, l'ArchaeoBIM si può configurare non solo come un altrettanto efficace contenitore di informazioni, ma risulta uno strumento ottimale proprio per la produzione di nuove informazioni sul contesto a partire dalla

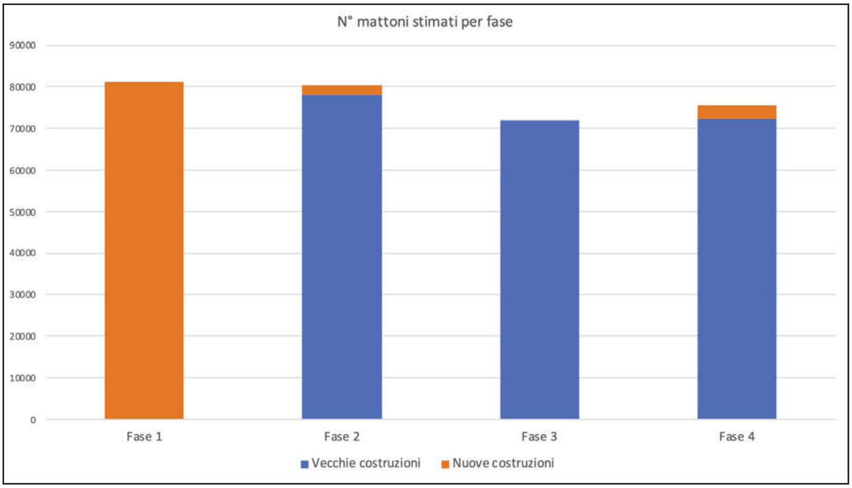

Fig. 6 – Grafico riportante la stima dell'uso di mattoni (28×18×12 cm) nelle varie fasi di vita dell'abitazione, differenziando per ogni fase le quantità riferibili allo stato di fatto.

verifica della sua fattibilità strutturale. La rigorosa strutturazione del dato architettonico permette infatti al software di elaborare informazioni complesse, che vanno ad incrementare la conoscenza del contesto stesso ben oltre l'aspetto visuale, producendo dati misurabili (e dunque confrontabili) quali il computo dei materiali utilizzati per la costruzione, il volume e la superficie degli ambienti, il rapporto tra le aree aperte e chiuse, fino ad arrivare a complesse simulazioni di tipo statico, termico o luminoso (Garagnani *et al.* 2021, 95-97). L'elaborazione del modello BIM della Casa 1 (Fig. 5) ha permesso così di stimare efficacemente l'impiego diversificato di materiale edilizio nelle varie fasi dell'abitazione, quantificando con buona approssimazione l'uso delle risorse nel tempo (Fig. 6).

L'efficacia dell'ArchaeoBIM risulta però vincolata agli elementi che possono essere inquadrati nelle famiglie BIM e come tali generati parametricamente e processati dal sistema. Elaborato per l'architettura moderna, l'adattamento di questo processo al mondo antico non risulta pertanto privo di complicazioni e pone alcuni problemi nell'inserimento di elementi architettonici non parametrizzabili (e.g. decorazioni architettoniche) o non contemplati dal moderno codice edilizio (e.g. antefisse). Tutto ciò che esula da questo tipo di parametrizzazione può comunque essere inserito nel sistema sotto forma di geometria poligonale, ma con importanti limitazioni sul piano dell'analisi, circoscritta in questo caso al solo aspetto visuale. Va inoltre sottolineato che il processo di modellazione BIM, proprio per la natura parametrica del processo di costruzione delle geometrie, tende a produrre modelli piuttosto schematici sotto il profilo grafico e si può affermare che i relativi software non dispongono delle potenzialità espressive sul piano grafico dei programmi di modellazione poligonale tradizionali.

Sulla base delle considerazioni sopra esposte emerge come, a parità di obiettivi, i modelli BIM presentano prospettive di analisi più stimolanti per quanto riguarda la sperimentazione, pur rimanendo maggiormente limitati sul piano della restituzione visuale di dettaglio. Per contro, i prodotti elaborati in un modellatore poligonale presentano un alto grado di potenzialità espressiva sul piano della resa grafica, privi della limitazione derivante dalla strutturazione per famiglie tipica dell'ambiente BIM, configurandosi come strumenti di gran lunga superiori per quanto riguarda l'aspetto della visualizzazione pura e semplice.

3. Il caso studio: la Casa 1 (R. IV, 2) di *Kainua*-Marzabotto

Come anticipato il contesto della Casa 1 della R.IV, 2 di *Kainua*-Marzabotto ha costituito la cornice in cui condurre le sperimentazioni su entrambe le metodologie. L'abitazione costituisce sicuramente uno dei contesti più stimolanti del sito di Marzabotto su cui impostare una ricostruzione virtuale, in ragione della sua lunga e articolata sequenza di fasi edilizie e delle molteplici soluzioni architettoniche adottate. L'abitazione presenta quattro fasi edilizie a partire dalla fondazione databile tra la fine del VI e gli inizi del V secolo a.C. fino all'abbandono nell'inoltrato IV secolo a.C. (Govi 2010). Nel corso degli anni la Casa 1 è già stata protagonista di diverse proposte ricostruttive (Beltrami 2010; Govi 2016, fig. 4; cfr. anche https://e-archeo.it/marzabotto/), volte a restituirne specifiche fasi o distinte aree, ma risultava ad oggi ancora priva di un modello che ne descrivesse integralmente tutte le varie evoluzioni nel corso del tempo.

Il prodotto che si presenta nasce proprio con questo specifico intento, cioè quello di restituire estensivamente tutte le fasi edilizie della casa, dall'esordio alla dismissione, all'interno di un unico sistema informativo che permetta, oltre alla visualizzazione, anche la consultazione delle informazioni usate per la sua realizzazione (Mancuso 2023b). Tra i vari intenti, oltre alla gestione del dato multifase, di primaria importanza è anche quello di riconsiderare con nuovi mezzi il problema delle coperture degli edifici che compongono la casa, anche alla luce delle numerose riflessioni fatte per il sito di Marzabotto (Gruška *et al.* 2017).

Tenuto conto delle particolarità metodologiche dei due processi di ricostruzione, si è cercato di procedere all'elaborazione del modello della Casa 1 integrando i due metodi. Considerate le limitazioni imposte dai modellatori BIM sul piano grafico, e dunque l'impossibilità di sostituire al modello di rappresentazione del processo EM un prodotto BIM, il punto di giunzione

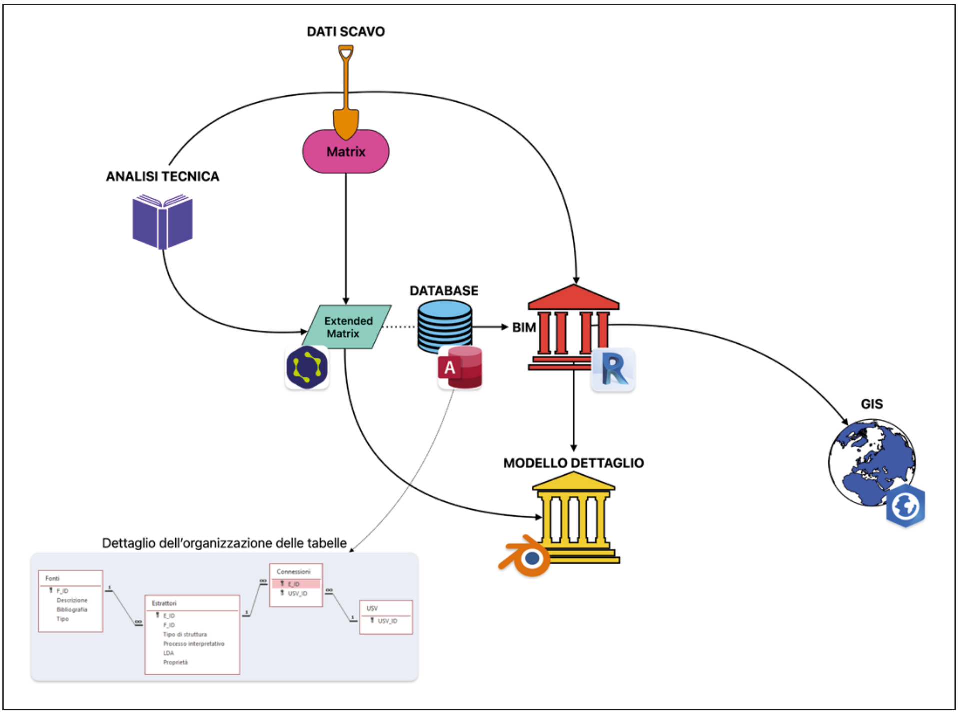

Fig. 7 – Mappa concettuale del processo di integrazione tra ArchaeoBIM ed EM. In basso a sinistra: dettaglio dello schema di relazioni tra le tabelle nel database.

tra i due processi è diventata la realizzazione del modello proxy dell'edificio, che è stato modellato mediante un processo ArchaeoBIM. Si è infatti precedentemente osservato come entrambi i metodi abbiano fondamentalmente il medesimo punto di partenza, ovvero il rilievo del contesto, l'analisi tecnica dell'edificio e la definizione delle fasi edilizie dello stesso. Il primo step ha dunque riguardato il recupero della documentazione e la realizzazione di una tabella delle fonti da utilizzare nel corso della ricostruzione. La casa, scavata tra il 1988 e il 1998, risulta priva di documentazione nativamente digitale e le fondazioni in ciottoli sono state ricoperte al termine delle operazioni di scavo per ragioni di conservazione. Considerata dunque l'impossibilità di procedere sul campo con un rilievo 3D delle strutture, la documentazione topografica di base su cui impostare la ricostruzione è quella costituita dall'insieme di planimetrie, sezioni e prospetti poi confluiti nella pubblicazione integrale dello scavo (Govi, Sassatelli 2010). A questa si è aggiunta l'elaborazione del matrix dello scavo, che ha costituito il punto di partenza per la realizzazione dell'EM (Mancuso 2023b).

Questi dati, elaborati nel corso della modellazione sotto forma di grafo, sono stati parallelamente trasferiti anche in un database, costruito su quattro tabelle: fonti, estrattori, connessioni e USV. La struttura pluri-tabellare del database è funzionale alla gestione delle relazioni uno-a-uno tra le tabelle fonti ed estrattori e quelle uno-a-molti tra gli estrattori e le USV, passando per la tabella connessioni (Fig. 7). Nel corso dell'elaborazione dell'EM si è infatti osservato che la descrizione di alcune proprietà, come l'altezza dei muri, tendesse a basarsi sui medesimi processi deduttivi, ripetibili per la quasi totalità delle strutture modellate. Dunque, nell'ottica di ottimizzare la realizzazione del grafo eliminando inutili ripetizioni di informazioni, si è preferito, dove possibile, descrivere la medesima proprietà di molteplici USV con un'unica rete di nodi estrattori-fonti. Il grafo è stato sviluppato nel software yEd usando la palette di nodi dell'EM; nella sua trasposizione tabulare si è tralasciato l'uso dei nodi di proprietà, che nel processo EM sono connessi direttamente alle USV. Il tipo di proprietà architettoniche che gli estrattori definivano è stato infatti integrato nella descrizione dell'estrattore stesso, rimandando così ai parametri del tipo del modello BIM per la loro applicazione.

Parallelamente a questo processo si è proceduto alla modellazione BIM delle strutture architettoniche, elaborate contemporaneamente alla costruzione dell'EM. Il modello BIM è stato elaborato in Autodesk Revit 2022. Tra gli innumerevoli vantaggi di questo software è rilevante menzionare, per quanto riguarda il processo di integrazione delle due metodologie, la possibilità di connettere il progetto ad un database per la gestione differenziata delle tabelle generate dal sistema e per l'importazione e l'esportazione dei metadati. La connessione tra i due strumenti (l'elaborazione in tabella del grafo descrittivo dell'EM e il BIM) è possibile attraverso la definizione in quest'ultimo di parametri condivisi, utilizzabili come foreign key nella relazione tra i paradati delle istanze BIM e i record della versione tabulare dell'EM. L'unico parametro necessario per raccordare le informazioni tra i diversi strumenti è il campo US, che è stato aggiunto alla tabella dei dati di identità delle geometrie in Revit.

Rispetto al flusso di lavoro proposto per l'EM, l'unica problematica cui si è dovuto fare fronte, aggiustando lievemente il processo, riguarda la gestione delle fondazioni che in ambiente BIM, sulla scia della logica del processo costruttivo, si configurano come elementi direttamente dipendenti dai muri e difficilmente gestibili come entità autonome. Il problema si è posto dunque per quelle fondazioni che presentano porzioni conservate (e descritte dunque da US) e lacerti mancanti (reintegrati da USV). In ambiente BIM la replica di tale suddivisione presupporrebbe il frazionamento dei muri soprastanti, generando parcellizzazioni artificiali all'interno della medesima azione costruttiva. In questi casi si è generato in EM un nuovo tipo di nodo denominato USR (Unità Stratigrafica Restaurata) a cui sono stati connesse le USV dei muri; la stessa nomenclatura è stata poi seguita anche in Revit.

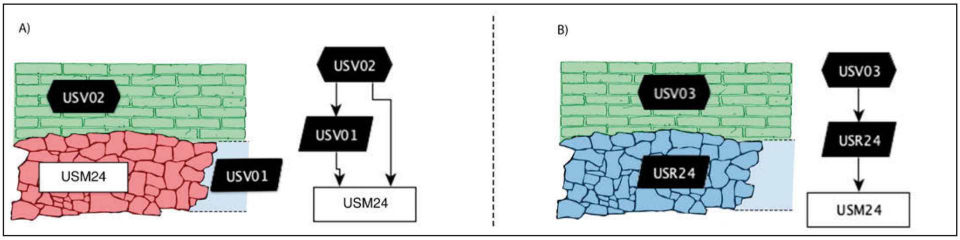

Fig. 8 – Schema dell'uso delle USR (B) rispetto all'uso tradizionalmente suggerito nel processo EM (A).

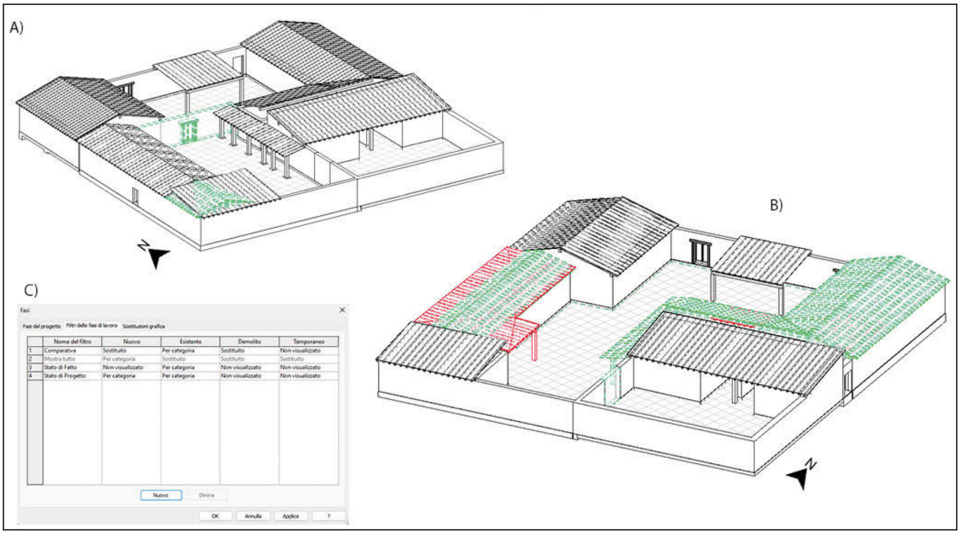

Fig. 9 – Particolari della gestione dei dati strutturali della Casa 1 in Revit. A) Fase 2, in verde le modifiche intercorse con la fase precedente; B) Fase 3, in rosso le modifiche intercorse con la Fase 2 e in verde quelle con la Fase 1; C) particolare della tabella di filtro delle fasi.

Alle USR sono stati assegnati i medesimi numeri delle US, al fine di evitare una ulteriore moltiplicazione della nomenclatura procedendo anche per le prime in modo crescente a partire da 1; così, ad esempio, l'operazione di restauro virtuale della fondazione US4, pur essendo la prima, viene descritta da USR4 (Fig. 8).

L'elaborazione della ricostruzione della casa ha posto numerosi spunti di riflessione, sia sul piano delle tecniche costruttive utilizzate, che su quello dell'elaborazione delle coperture, da sempre un aspetto problematico delle ricostruzioni di Marzabotto (Gruška *et al.* 2017). L'elaborazione del modello informativo mediante EM esime dalla necessità di descrivere puntualmente

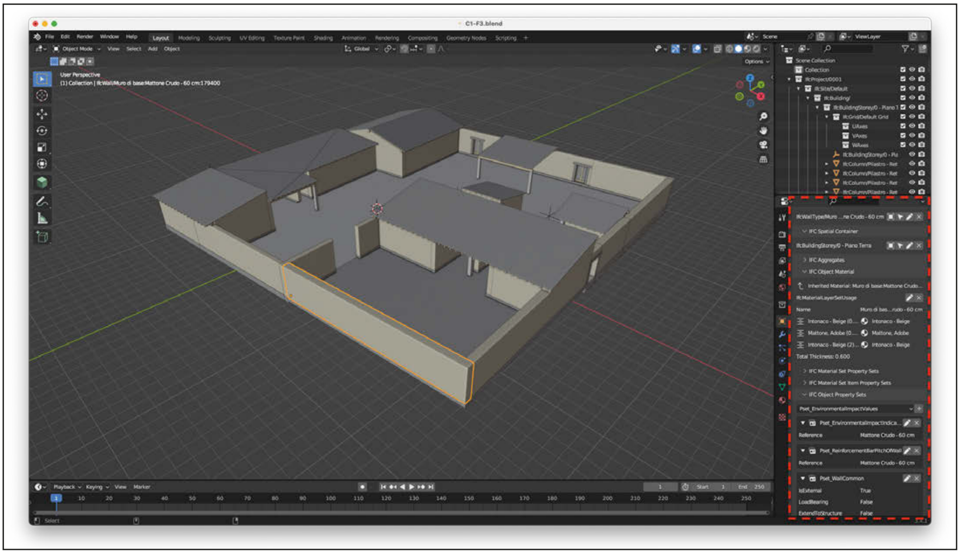

Fig. 10 – Modello BIM della Casa 1 (Fase 3) importato in Blender in formato IFC. In evidenza a destra una parte delle proprietà BIM dell'oggetto selezionato.

le soluzioni architettoniche presentate, rimandando a questo strumento la giustificazione delle scelte operate sul piano archeologico (Mancuso 2023b). Su un piano più tecnico, va infine sottolineato come gli strumenti messi a disposizione da Revit si rivelino ottimali per l'elaborazione di un singolo modello contenente tutte le fasi edilizie del complesso. Frequentemente, infatti, la visualizzazione di prodotti multifase pone alcuni problemi, soprattutto nei casi in cui il contesto vede una costante successione di parziali demolizioni e rifacimenti dei medesimi corpi di fabbrica con strutture realizzate riutilizzando una parte di quelle della fase precedente. Risulta così difficile filtrare visivamente le costruzioni che vengono edificate in un determinato periodo e permangono nel corso delle fasi successive, in quanto scompaiono al cambiamento dei parametri della ricerca per singola fase. In Revit, la possibilità di differenziare per ogni istanza le fasi di costruzione e demolizione si è rivelata fondamentale nella restituzione del contesto in prospettiva diacronica. Questo accorgimento, accompagnato ad un altrettanto efficace filtro di fase (che permette di differenziare la visualizzazione per categorie tra elementi di nuova realizzazione, precedenti e demoliti) consente di accedere in maniera particolarmente intuitiva a forme avanzate di visualizzazione e gestione di dati multifase (Fig. 9).

Tale configurazione, benché funzionale in ambiente Revit, presenta purtroppo alcune problematiche nell'esportazione dei dati del modello verso altri software dove questi strumenti di visualizzazione mancano. Così, al termine dell'elaborazione della ricostruzione multifase, le quattro fasi edilizie sono state suddivise in altrettanti progetti BIM, in cui le costruzioni riferibili a fasi precedenti sono rientrate nello "stato di fatto", mentre quelle della fase corrente nello "stato di progetto". Al termine dell'elaborazione del modello proxy in BIM, lo stesso è stato esportato in Blender in formato IFC, dove, grazie all'add-on BlenderBIM, i dati relativi alle famiglie e i tipi vengono letti e rimangono consultabili (Fig. 10). Questo passaggio risulta fondamentale non solo per la prosecuzione del processo EM, ma anche per implementare l'accessibilità del prodotto BIM, che si svincola così dal software proprietario con cui viene elaborato, e favorirne la sua sostenibilità a lungo termine in accordo agli omologhi principi della carta di Londra (London Charter 2009). In Blender il modello IFC può essere connesso con il grafo EM, rendendo disponibili alla consultazione anche i dati di quest'ultimo strumento nel suo flusso di lavoro originario (Demetrescu, Ferdani 2021). Dal medesimo software è poi possibile elaborare il modello di dettaglio e procedere alla pubblicazione dei dati, secondo il flusso di lavoro già elaborato per il processo EM.

4. Considerazioni conclusive e prospettive future

Al termine di questo processo, finalizzato all'integrazione tra le due metodologie applicate al contesto della Casa 1, sembra lecito formulare alcune considerazioni conclusive. In primo luogo, va sottolineato come l'integrazione tra i due metodi di ricostruzione sia possibile, benché perfettibile ottimizzandone il flusso di lavoro. Il processo dell'EM si rivela infatti ottimale per la descrizione semplificata di dati complessi, a partire da quelli archeologici. Proprio la forte devozione al dato archeologico del metodo permette di giustificare più che adeguatamente le scelte ricostruttive operate nel corso del processo.

La struttura del grafo, se da un lato permette di gestire intuitivamente le relazioni molti-a-molti che intercorrono tra fonti ed estrattori di informazioni, d'altro canto, però, non sembra altrettanto intuitivo come strumento di descrizione progettuale. Questo problema emerge soprattutto in contesti che, come nel nostro caso, sono costituiti quasi esclusivamente da USV e nei quali, dunque, la descrizione dello sviluppo verticale degli elementi architettonici della struttura per mezzo del grafo risulta quasi pleonastica e sostituibile con la sua stessa rappresentazione grafica. Infatti, in assenza di elementi architettonici di cui fare anastilosi, il grafo traduce fondamentalmente una sequenza di fondazioni, murature, strutture di supporto del tetto ed elementi di copertura, cioè una successione altrettanto ben apprezzabile per mezzo della sua rappresentazione grafica. Nel nostro caso dunque, la sostituzione

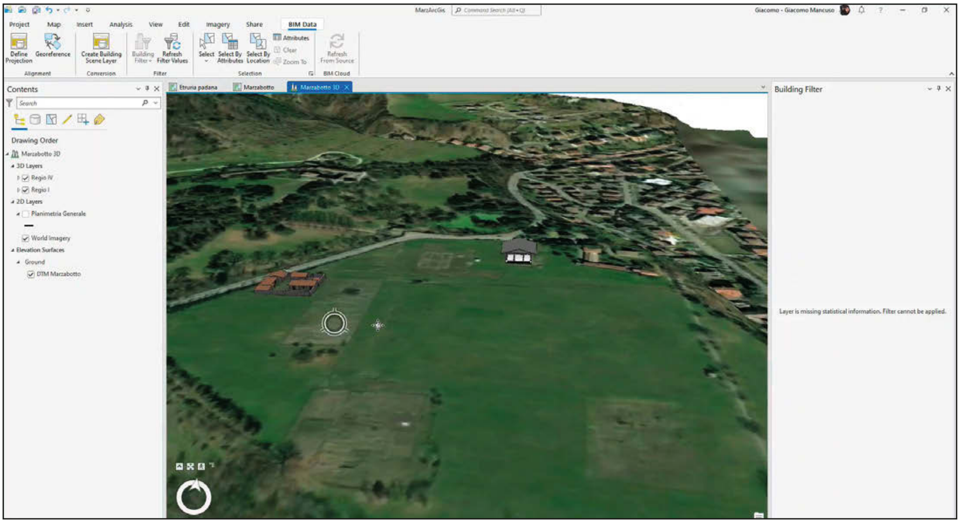

Fig. 11 – Vista generale della scena ArcGIS contenente i modelli Revit della Casa 1 (a sinistra) e del Tempio di Uni (a destra).

o l'uso parallelo del grafo con un database tabulare connesso alle geometrie parametriche in ambiente BIM si sono rivelati altrettanto efficaci, permettendo una adeguata giustificazione delle scelte strutturali operate sulla base dei dati archeologici e architettonici.

Se dunque il processo EM consente di esprimere efficacemente l'uso delle fonti nella ricostruzione, l'ArchaeoBIM permette di approdare in maniera più che efficace e ben oltre l'aspetto visuale alla descrizione di un edificio che potrebbe essere esistito in passato, aprendo ad una serie di sperimentazioni che possono incrementare le conoscenze del contesto sul piano architettonico e strutturale (Garagnani *et al.* 2021, 95-97). L'uso congiunto di entrambe le metodologie colma le lacune dell'ArchaeoBIM nella ricostruzione di elementi non parametrizzabili in famiglie architettoniche, la cui ricostruzione può essere tralasciata nel modello BIM, per essere poi elaborata successivamente nel modello di restituzione e descritta dall'EM.

Un ulteriore interessante sviluppo analitico dell'integrazione di questi due processi ricostruttivi consiste poi nella possibilità di importare e gestire i modelli BIM in ambiente GIS (Fig. 7). Sotto un profilo tecnico questa integrazione risulta configurabile solamente in ArcGis Pro, dove è possibile collegare un progetto realizzato in Autodesk Revit direttamente nel suo formato nativo. L'aspetto interessante è proprio la possibilità di gestire dinamicamente tutti gli aspetti informativi che caratterizzano il progetto BIM, integrandoli con gli altri tipi di dati ospitabili all'interno di un sistema informativo territoriale.

Nello specifico caso di Marzabotto, è stata dunque configurata una scena 3D impostata sul DTM della città antica (Gaucci *et al.* 2015, 2022; Muzzarelli, Franzoia 2017; Mancuso 2023a), sul quale sono stati caricati i dati relativi alle infrastrutture e alle ripartizioni urbanistiche, oltre alla planimetria generale dell'insediamento (Fig. 11).

All'interno di questa scena sono stati posizionati i modelli BIM della Casa 1 e del tempio di *Uni* (Garagnani *et al.* 2016b, 2021, 101-122, 146-154; Garagnani 2017, 145-149). Nonostante la preliminarità di questa specifica fase della ricerca, emerge come l'integrazione tra BIM e GIS arricchisca due aspetti chiave della VA: la visualizzazione e l'analisi. Per quanto riguarda la prima, il progressivo popolamento della scena con modelli BIM renderà possibile accedere a nuove forme di visualizzazione spaziale del dato architettonico su scala urbanistica, molto utili per organizzare visualmente dataset complessi in ragione della cronologia o di specifici elementi, caratterizzandoli proceduralmente in ragione di uno o più attributi. Dal momento che il modello mantiene i parametri condivisi impostati nel progetto Revit, risulta possibile variarne la simbologia sulla base di specifiche caratteristiche, analogamente a qualsiasi altro dato vettoriale in ambiente GIS. La possibilità di collegare mediante join questi attributi con altri dati tabulari amplifica poi esponenzialmente le possibilità di visualizzazione. A un livello molto basilare gli edifici possono così essere caratterizzati su scala urbana con colori differenti a seconda del livello di affidabilità della ricostruzione o in ragione del materiale da costruzione utilizzato.

Il secondo aspetto riguarda ovviamente l'analisi dei dati e più specificatamente degli attributi degli elementi architettonici. La natura del BIM come database 3D permette infatti di estendere in GIS l'elaborazione di abachi e computi a molteplici modelli nella medesima scena, elaborando dataset utili per l'analisi dell'impatto umano sul territorio antico e aprendo a riflessioni sul carico degli insediamenti sul territorio circostante, stimando, ad esempio, il consumo di materiale per l'edilizia in specifiche fasi cronologiche e il conseguente irraggiamento sul territorio in funzione delle risorse.

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BIBLIOGRAFIA

Beltrami F. 2010, *La ricostruzione virtuale della Casa 1. Una proposta*, in Govi, Sassatelli 2010, 283-287.

Demetrescu E. 2015, *Archaeological stratigraphy as a formal language for virtual reconstruction. Theory and practice*, «Journal of Archaeological Science», 57, 42-55 (https://doi.org/10.1016/j.jas.2015.02.004).

Demetrescu E. 2018, *Virtual reconstruction as a scientific tool: The Extended Matrix and source-based modelling approach*, in S. Münster, S. Friedrichs, F. Niebling, A. Seidel-Grzesińska (eds.), *Digital Research and Education in Architectural Heritage (UHDL DECH, Dresden 2017)*, Springer, Cham, 102-116 (https://doi.org/10.1007/978-3-319-76992-9_7).

Demetrescu E. 2022, *Extended Matrix. A Tool for Virtual Reconstruction in Archaeology* (https://www.extendedmatrix.org/).

Demetrescu E., Fanini B. 2017, *A white-box framework to oversee archaeological virtual reconstructions in space and time: Methods and tools*, «Journal of Archaeological Sience: Reports», 14, 500-514.

Demetrescu E., Ferdani D. 2021, *From field archaeology to virtual reconstruction: A five steps method using the Extended Matrix*, «Applied Sciences», 11, 5206 (https://doi.org/10.3390/app11115206).

Garagnani S. 2017, *Archaeological Building Information Modeling: Beyond scalable representation in architecture and archaeology*, in Garagnani, Gaucci 2017, 141-149 (https://doi.org/10.19282/AC.28.2.2017.09).

Garagnani S., Gaucci A. (eds.) 2017, *Knowledge, Analysis and Innovative Methods for the Study and the Dissemination of Ancient Urban Areas, Proceedings of the KAINUA 2017 International Conference (Bologna 2017)*, «Archeologia e Calcolatori», 28, 2 (http://www.archcalc.cnr.it/journal/idyear.php?IDyear=2017-01-07).

Garagnani S., Gaucci A., Govi E. 2016a, *ArchaeoBIM: dallo scavo al Building Information Modeling di una struttura sepolta. Il caso del tempio etrusco di Uni a Marzabotto*, «Archeologia e Calcolatori», 27, 251-270 (https://doi.org/10.19282/AC.27.2016.13).

Garagnani S., Gaucci A., Govi E. 2017, *Ancient reality and contemporary research. An introduction to the Conference KAINUA 2017 and its Proceedings*, in Garagnani, Gaucci 2017, 11-23 (https://doi.org/10.19282/AC.28.2.2017.01).

Garagnani S., Gaucci A., Gruška B. 2016b, *From the archaeological record to ArchaeoBIM. The case study of the Etruscan temple of Uni in Marzabotto*, «Virtual Archaeology Review», 7, 15, 77-86 (https://doi.org/10.4995/var.2016.5846).

Garagnani S., Gaucci A., Moscati P., Gaiani M. 2021, *ArchaeoBIM. Theory, Processes and Digital Methodologies for the Lost Heritage*, Bologna, Bononia University Press.

Gaucci A. 2017, *Kainua project: Principles, theoretical framework and archaeological analysis*, in Garagnani, Gaucci 2017, 99-112 (https://doi.org/10.19282/AC.28.2.2017.06).

Gaucci A., Garagnani S., Manferdini A.M. 2015, *Reconstructing the lost reality. Archaeological analysis and transmedial technologies for a perspective of virtual reality in the Etruscan city of Kainua*, in G. Guidi *et al.* (eds.), *2nd Digital Heritage International Congress, DigitalHERITAGE 2015 (Granada 2015)*, IEEE, 227-234.

Gaucci A., Garagnani S., Manferdini A.M., Dubbini M., Mancuso G. 2022, *Marzabotto, DTM della città etrusca* (https://doi.org/10.5281/zenodo.5734013).

Gerbino S., Cieri L., Rainieri C., Fabbrocino G. 2021, *On BIM interoperability via the IFC standard: An assessment from the structural engineering and design viewpoint*, «Applied Sciences», 11, 11430 (https://doi.org/10.3390/app112311430).

Giuliani C. F. 2006, *L'edilizia nell'antichità*, Roma, Carocci Editore.

Govi E. 2010, *L'analisi planimetrica e la ricostruzione delle fasi edilizie*, in Govi, Sassatelli 2010, 179-204.

Govi E. 2016, *L'architettura domestica di Marzabotto tra vecchi scavi e nuove indagini*, «Annali della Fondazione per il Museo "Claudio Faina"», 23, 187-241.

Govi E. 2017, *Kainua-Marzabotto: The archaeological framework*, in Garagnani, Gaucci 2017, 87-97 (https://doi.org/10.19282/AC.28.2.2017.05).

Govi E., Sassatelli G. (eds.) 2010, *Marzabotto. La Casa 1 della Regio IV – Insula 2*, Imola, Antequem.

Gruška B., Mancuso G., Zampieri E. 2017, *Building materials and virtual models of the Etruscan city of Kainua*, in Garagnani, Gaucci 2017, 165-176 (https://doi.org/10.19282/AC.28.2.2017.11).

Harris E. 1979, *Principles of Archaeological Stratigraphy*, Suffolk, Academic Press.

Harris E., Brown III M.R., Brown G.J. (eds.) 1993, *Practices of Archaeological Stratigraphy*, Cambridge, MA, Academic Press.

London Charter 2009, *London Charter for the Computer-based Visualization of Cultural Heritage, Draft 2.1-2009* (www.londoncharter.org).

Mancuso G. 2023a, *Marzabotto, Kainua 3D. Base GIS* (https://doi.org/10.5281/zenodo.7540522).

Mancuso G. 2023b, *Marzabotto, Regio IV, Insula 2, Casa 1. Modello ricostruttivo BIM* (https://doi.org/10.5281/zenodo.7540382).

Muzzarelli A., Franzoia M. 2017, *The ancient Digital Terrain Model and the infrastructure of the Etruscan city*, in Garagnani, Gaucci 2017, 151-164 (https://doi.org/10.19282/AC.28.2.2017.10).

Sassatelli G., Taglioni C. 2000, *Città etrusca di Marzabotto*, Bologna, HitStudio Editori.

Seville Charter 2012, *International Principles of Virtual Archaeology* (http://sevilleprinciples.com/).

Yu Hook D. 2016, *From illusions to reality: Transformation of the term "virtual archaeology"*, «Archaeological and Anthropological Sciences», 8, 4, 647-650.

ABSTRACT

The article systematically explores two processes of virtual reconstruction of archaeological contexts: ArchaeoBIM and Extended Matrix. The focus is on the theoretical frameworks behind their development, the proposed operational processes, and the products derived from both methodologies. The informative potential of the virtual models resulting from these reconstruction processes will be discussed, as well as the application-related issues. A substantial part of the article will be dedicated to the development of an integrative protocol aimed at incorporating the informational structure of the Extended Matrix within an ArchaeoBIM model. The process has been applied to the case study of House 1 in Regio IV, Insula 2 of the Etruscan city of Marzabotto, which was excavated in recent years (1988-1998) and thoroughly documented. Final considerations are then directed towards future development prospects and the integration of this virtual product within a Geographic Information System.

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LA NECROPOLI MESSAPICA DI MONTE D'ELIA AD ALEZIO (LECCE): INTEGRAZIONE DI RILIEVI TOPOGRAFICI E INDAGINI GEOFISICHE A SUPPORTO DELLE INDAGINI STRATIGRAFICHE

1. Introduzione

A partire dall'estate del 2020, dopo oltre trent'anni, sono ripresi gli scavi archeologici nella necropoli messapica di Monte D'Elia, posta circa 300 m a S di Alezio e già oggetto di indagini effettuate dalla Soprintendenza Archeologica per la Puglia tra il 1981 e il 1985. Queste ricerche portarono alla luce un vasto settore della necropoli, in uso lungo un ampio arco cronologico compreso tra VI e II sec. a.C., con tipologie funerarie comprendenti tombe a fossa terragna, sarcofagi e tombe a cassa di lastroni. Nonostante il clamore della scoperta, successivamente alle indagini il sito andò incontro a uno stato di progressivo abbandono e le sepolture subirono vari danneggiamenti per l'esposizione agli agenti atmosferici ed episodi di vandalismo. Pertanto, le aree indagate vennero nuovamente interrate nel 1989, in attesa di finanziamenti che potessero consentire un piano di recupero e musealizzazione delle evidenze archeologiche. Nel 2004 ciò fu possibile grazie alla realizzazione dell'attuale Parco Archeologico, provvisto di recinzione e tettoia a copertura delle sepolture; tuttavia, non tutte le tombe scoperte negli anni Ottanta furono riportate alla luce, ma solo un limitato e significativo gruppo posto nella porzione centro-meridionale del parco.

I nuovi scavi, condotti nel 2020 dal Dipartimento di Beni Culturali dell'Università del Salento, hanno visto la partecipazione di ricercatori dell'Istituto di Scienze del Patrimonio Culturale (ISPC) del CNR, a cui sono state affidate anche le attività di prospezione geofisica preliminari alle indagini stratigrafiche e quelle di rilievo topografico, effettuate sia con laser scanner che mediante l'utilizzo di un drone[1]. In attesa della pubblicazione dettagliata dei risultati degli scavi (notizie preliminari in Mastronuzzi, Melissano 2021, 327, fig. 6), il presente contributo è incentrato sulle attività di ricerca volte

[1] Gli scavi del 2020, realizzati a luglio, agosto e ottobre su concessione ministeriale MIC 1023 del 26/9/2019, sono stati diretti da Giovanni Mastronuzzi e hanno visto la partecipazione anche di Patricia Caprino, Ivan Ferrari e Francesco Solinas. Le attività di ricerca, rese possibili anche grazie al supporto della Soprintendenza Archeologia Belle Arti e Paesaggio per le Province di Brindisi e Lecce (Funzionario Archeologo di zona: Serena Strafella), sono state svolte nell'ambito di una convenzione operativa tra il Dipartimento di Beni Culturali dell'Università del Salento, l'ISPC-CNR e il Comune di Alezio, firmata nel 2019. Nello specifico, le indagini e i rilievi che qui si presentano sono stati realizzati da tre laboratori della Sede di Lecce dell'ISPC-CNR: il Digital Heritage Innovation Lab, il Geophysics Lab e l'Archaeological Mapping Lab.

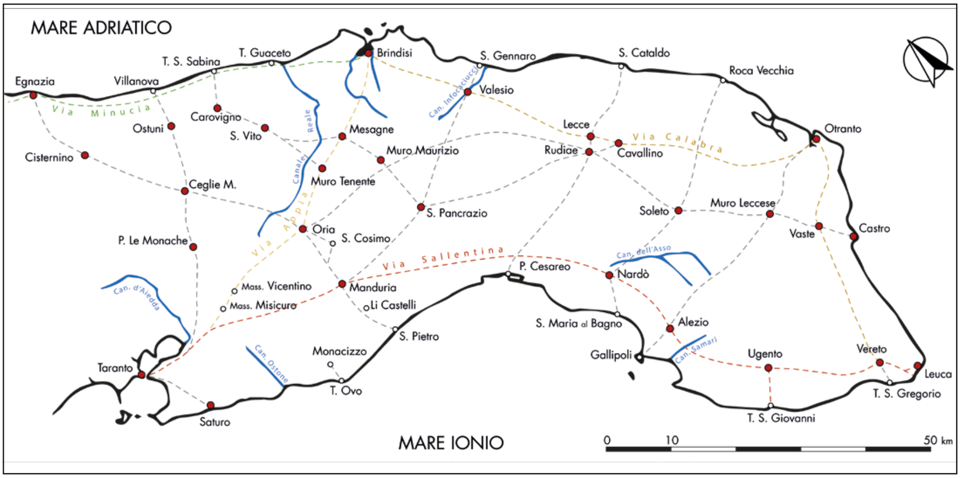

Fig. 1 – Alezio nell'ambito della viabilità preromana della Messapia (rielab. da Uggeri 1975, 80).

a definire la planimetria generale della necropoli, integrando i risultati delle ricerche degli anni Ottanta con quelli delle nuove indagini, e, più in generale, alla ricostruzione della sua organizzazione topografica ed estensione.

I.F., F.G., G.L., G.S.

2. Alezio tra i centri della Messapia meridionale

L'antica Alezio occupava una modesta altura (73 m s.l.m.) oggi dominata dalla chiesa tardo-medievale di S. Maria della Lizza o dell'Alizza, strategica per il presidio della fertile pianura litoranea che si estendeva sino all'approdo gallipolino, distante circa 7 km, un porto naturale cruciale per il controllo dei traffici marini lungo la costa ionica pugliese. L'abitato, menzionato in varie fonti classiche come ʽΑλητία (Strabo, *Geogr*., VI, 3,6), *Aletium* (Plin., *Nat. Hist*., III, 11, 105, 100-101), ʽΑλήτιον (Tol., *Geogr*., III, 1, 67), *Baletium* (*Tab. Peut*., VI,5-VII,2; Rav. Anom., *Cosmogr*., V, 1) e *Valentium* (Guido, *Geogr*., 72), si estendeva anche in direzione E su un'area pianeggiante denominata Raggi (65 m s.l.m.).

Alezio costituiva uno snodo viario importante nei tracciati di epoca messapica e poi romana, in quanto posto lungo il percorso paralitoraneo che collegava Taranto ai più importanti centri dell'arco ionico sino al Capo di Leuca e costituiva il caposaldo di uno dei percorsi istmici che congiungeva le due sponde della penisola salentina (Uggeri 1975, 1983; Lombardo 1992, 101-102, 126) (Fig. 1). Purtroppo la conoscenza di questo importante sito, salvo alcune eccezioni, si basa perlopiù su una numerosa serie di rinvenimenti occasionali avvenuti con regolarità a partire dalla seconda metà del Settecento, durante interventi legati a lavori edili e attività agricole (Ferrari, Scardozzi 2016, 19-53); inoltre, la progressiva sovrapposizione della moderna cittadina su quasi tutta l'area dell'antico insediamento rende difficoltosa la ricostruzione della sua organizzazione topografica in epoca messapica e romana.

Nonostante ciò, è comunque possibile tracciare le linee generali della sua evoluzione storica a partire dalla tarda età del Ferro (Ferrari, Scardozzi 2016, 140-158), cui è verosimile far risalire un abitato di capanne simile a quelli attestati in altri insediamenti messapici di fine VIII-VII sec. a.C. (De Mitri 2020, 9-12). Certamente Alezio fu un insediamento di una certa importanza già nel VI sec. a.C., ma non sappiamo se fu interessato in questo periodo dallo stesso sviluppo urbano che caratterizzò altri abitati messapici, come per esempio Cavallino, Oria o Ugento. Stando alla distribuzione dei reperti di età arcaica e classica, è probabile che in questa fase la località Raggi fosse almeno in parte periferica rispetto al centro abitato, che poteva essere concentrato sulla collina della Lizza, occupando una superficie non definibile con certezza, la cui estensione è stimata tra 14 e 24 ettari. L'abitato era caratterizzato da nuclei di case con fondamenta in pietra alternati a spazi liberi, in parte utilizzati anche come necropoli. Tra queste ultime, già in questa fase era in uso quella di Monte d'Elia, che si sviluppava subito a S dell'insediamento.

Pochi sono i dati per l'età classica, mentre maggiori sono quelli a disposizione per il periodo ellenistico (seconda metà del IV-prima metà del III sec. a.C.), anche se non esaustivi per una comprensione dello sviluppo urbano, che per analogia con altri centri coevi si ipotizza potesse prevedere in questa fase anche la costruzione di un circuito murario a protezione dell'abitato, racchiudendo la collina della Lizza e la località Raggi (D'Andria 1991, 447; Lamboley 1996, 241). A tal proposito, sulla base delle tracce visibili nelle fotografie aeree degli anni Quaranta del '900, è stato ipotizzato un perimetro di circa 3400 m che racchiudeva una superficie di circa 67 ettari, estensione che consente di collocarlo tra i centri di medie dimensioni della Messapia. Anche in questa fase alcune aree funerarie sono immediatamente a ridosso di quelle abitate, come sul versante meridionale della collina della Lizza (De Mitri 2020, 2-9), mentre a S dell'insediamento continua l'utilizzo dell'importante necropoli di Monte d'Elia.

Uno degli aspetti che contraddistingue Alezio in epoca messapica riguarda senza dubbio la documentazione epigrafica, poiché si tratta del centro che ha restituito il maggior numero di attestazioni, databili tra VI e II sec. a.C., tutte sostanzialmente provenienti da contesti funerari. Tra questi, nonostante siano noti alcuni nuclei di tombe in vari settori dell'abitato – come sulla collina della Lizza, nelle località Tafuri e Raggi, oltre che nell'area del centro storico di Villa Picciotti (Ferrari, Scardozzi 2016, 140-144, 148-150) – spicca proprio il sito di Monte d'Elia, che sembra costituire la più importante area sepolcrale riferibile all'insediamento messapico; collocata su una bassa altura poco a S dell'abitato, questa necropoli sorgeva in prossimità del tracciato che collegava i centri messapici subcostieri dell'arco ionico (la cd. *via Sallentina*) e che in questo punto usciva da Alezio per raggiungere Ugento.

Dopo la conquista romana del Salento (267-266 a.C.), Alezio conservò un ruolo di una certa importanza nel quadro della regione sino alla guerra annibalica, successivamente alla quale si avviò, nel corso del II sec. a.C., un generale processo di romanizzazione cui lo stesso centro non fu risparmiato e che portò al progressivo abbandono degli usi della tradizione messapica sino a quel momento ancora tangibili. L'impianto urbano sembra non mutare in età imperiale, salvo assumere un'organizzazione più regolare in località Raggi, la cui porzione orientale si contraddistingue per l'installazione di impianti produttivi (fornaci per ceramica, strutture per la produzione di vino e olio). Nonostante i ritrovamenti ceramici attestino un'occupazione dell'area almeno sino al VII-VIII sec. d.C., in generale in questa fase si assiste a un progressivo abbandono delle strutture abitative e a uno spopolamento dell'insediamento, controbilanciato dall'affermazione, sulla costa, di Gallipoli come centro egemone dell'area.

I.F.

3. La necropoli di Monte d'Elia: gli scavi del 1981-1985

Le ricerche archeologiche del 1981-1985 hanno interessato vari settori della necropoli, mettendo in luce complessivamente circa 60 tombe, i cui corredi ne attestano un utilizzo tra VI e II sec. a.C. (De Juliis 1982, 303-304; 1983, 513; 1984, 431; 1985, 212; Andreassi 1986, 380; Ciongoli 1990, 197-198; Zezza 1991, 5-6; Lamboley 1996, 241-242; De Pascalis 2000-2001, 89-119, n. 26; D'Elia 2001, 20; De Santis, Congedo 2010, 179; Ferrari, Scardozzi 2016, 97-112). Le tipologie funerarie identificate variano dalle fosse terragne con copertura costituita da una rozza lastra di calcarenite locale, databili in età arcaica, ai sarcofagi monolitici e alle tombe a cassa di lastroni, sempre in calcarenite, in uso tra V e III sec. a.C. In alcuni casi, anche stando ai risultati degli scavi più recenti, è possibile comunque ipotizzare che le presunte tombe terragne di epoca arcaica siano piuttosto riduzioni di sepolture più antiche, collocate all'esterno di tombe a cassone o a sarcofago (a cui sono spesso accostate) per fare spazio a sepolture successive. Sono stati anche rinvenuti vari cippi anepigrafi in calcarenite, di forma parallelepipeda (misure esemplificative: base 34×22 cm, alt. 65), associati sia a tombe arcaiche che ellenistiche (Pagliara 1983, 35-36; Ciongoli 1990, 198; Lombardo 1994, 33-34).

La documentazione di questi scavi risulta incompleta, i corredi editi sono pochi e le planimetrie sono incoerenti tra loro e prive di georeferenziazione;

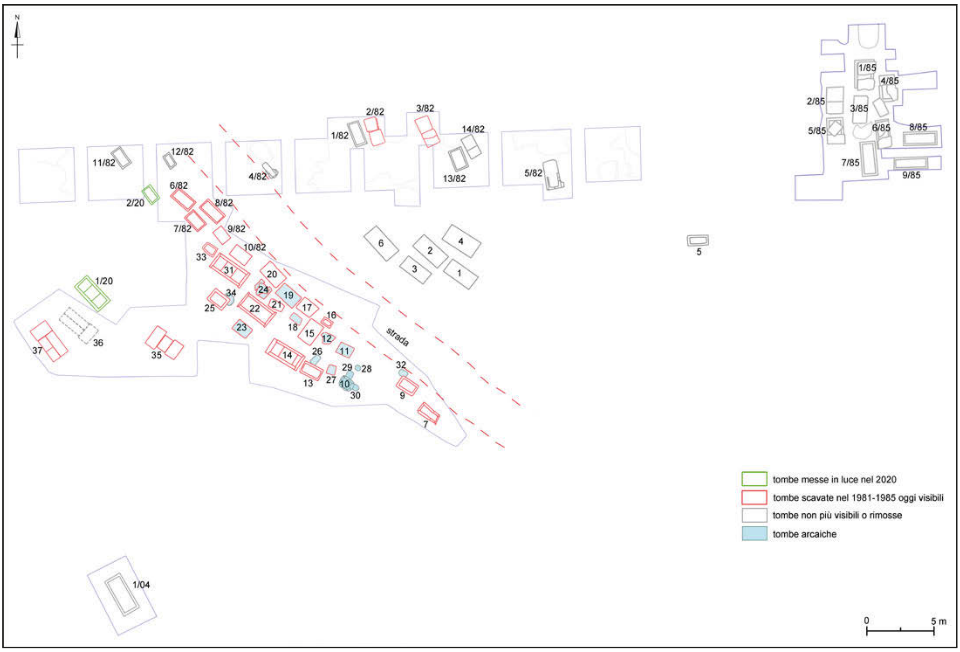

Fig. 2 – Planimetria generale della necropoli di Monte d'Elia ottenuta integrando e correggendo le planimetrie degli anni Ottanta del XX secolo con i recenti rilievi.

inoltre, il rinterro del 1989 ha reso difficoltosa la realizzazione di una pianta generale della necropoli. Solo grazie alla porzione del sepolcreto rimessa in luce nel 2004, che comprende gran parte delle tombe indagate nel 1981 e tre di quelle scavate nel 1982, è stato possibile georeferenziare le varie planimetrie disponibili (Fig. 2), in modo da avere un quadro complessivo della necropoli (*infra* § 5.2).

Lo scavo meglio documentato è quello del 1981, che interessò un'area estesa per 35 m in senso EO e 17 m in senso NS e portò alla scoperta di 37 tombe. Quelle riferibili a epoca arcaica in base alla tipologia e ai corredi, databili fra il VI e gli inizi del V sec. a.C., sono almeno dieci (nn. 8, 10, 11, 12, 18, 19, 23, 24, 26, 29), a cui si possono probabilmente aggiungere anche le tombe nn. 28, 32, 34. A eccezione della tomba n. 19, che è un sarcofago (1×1,65 m) e che si data tra la fine del VI e gli inizi del V sec. a.C., sono tutte costituite da sepolture a fossa terragna o scavata nel banco calcareo (misure esemplificative 60×80 cm), coperte da una lastra di calcarenite (dim. max 0,85×1,25 m); il defunto si presenta in posizione rannicchiata e i corredi comprendono un numero esiguo di oggetti (Semeraro 1997, 39-43; De Santis, Congedo 2010, 180-181; Mastronuzzi 2011, 6-11; Ferrari, Scardozzi 2016, 102-104).

Il confronto di quanto oggi conservato con le foto e i rilievi effettuati nel 1981 (Zezza 1991, fig. 3; D'Elia 2001, fig. 6) evidenzia come le tombe arcaiche nn. 10, 26, 28, 29, 30 e 34 siano state distrutte nel corso dello scavo del 2004, mentre i resti delle tombe nn. 12 e 24 siano stati leggermente spostati rispetto alla posizione di rinvenimento. Incerta invece la localizzazione della tomba n. 8, oggi non conservata e assente anche nelle planimetrie disponibili.

Il gruppo più consistente delle sepolture messe in luce nel 1981 è costituito dalle tombe a sarcofago (nn. 5, 9, 13, 15, 16, 17, 21, 25, 33) e a cassa di lastroni (nn. 1, 2, 3, 4, 5, 6, 7, 14, 20, 22, 31, 35, 36, 37), di cui quattro (nn. 1, 2, 3, 6) sono state trasferite nel giardino del Museo Civico Messapico di Alezio; le sepolture hanno restituito corredi datati tra V e III sec. a.C. Tra i sarcofagi, il n. 5 (1,65×0,65 m, alt. 45 cm), rinvenuto a E dell'area indagata e associato a un cippo, è stato anch'esso trasferito nel giardino del Museo Civico, mentre altri tre (nn. 16, 21, 33) presentano dimensioni molto ridotte (per esempio 50×80 cm). Tra le tombe a cassa (misure esemplificative: lungh. 1,74-2,97 m, largh. 0,86-1,33 m, alt. 0,70-1,20 m), spesso caratterizzate da lastre di copertura provviste di incavi per l'impugnatura, otto (nn. 1, 2, 3, 4, 6, 20, 22, 31) hanno restituito iscrizioni messapiche incise sulle facce interne di uno dei lastroni laterali delle casse, databili tra seconda metà del V e fine III - inizi II sec. a.C. e recanti i nomi dei proprietari (Santoro 1981, 51-55, 58-64; 1983, 88-113; 1984, 83-91; 1986, 361-370; De Simone, Marchesini 2002, 68-72; Ferrari, Scardozzi 2016, 68-70, *IMA* 46-53). I corredi di queste sepolture, che in alcuni casi scendono fino al II sec. a.C. (per esempio le tombe nn. 14, 31), documentandone l'utilizzo per più generazioni, attendono ancora uno studio accurato (dati preliminari in Lamboley 1996, 243; De Santis, Congedo 2010, 179; Ferrari, Scardozzi 2016, 105-112).

Lo scavo del 1982 interessò una fascia larga quasi 50 m in senso EO, posta subito a N di quella indagata nel 1981, dove si operò con saggi regolari di 4×4 m, in alcuni casi ulteriormente allargati. Vi si rinvennero almeno 11 tombe a sarcofago e a cassa di lastroni (nn. 1/82-11/82), a cui ne vanno forse aggiunte altre tre (nn. 12/82-14/82), documentate solo da uno dei rilievi disponibili (Zezza 1991, fig. 2; D'Elia 2001, fig. 5; Ferrari, Scardozzi 2016, fig. 41, con modifiche); solo le tombe a sarcofago nn. 6/82-10/82 sono state rimesse in luce nel 2004, mentre il resto è stato lasciato interrato, così come tutte le tombe (almeno nove), sempre a sarcofago e cassa di lastroni, indagate nel 1985 più a E, dove fu aperto un saggio di circa 11×8 m. Qui, tre tombe (misure esemplificative delle casse: lungh. 1,25-2,23 m, largh. 80-88 cm, alt. 60 cm) hanno restituito epigrafi messapiche di IV-III sec. a.C. (Santoro 1991, 411-417; De Simone, Marchesini 2002, 76-77; Ferrari, Scardozzi 2016, 61, 70-71, *IMA* 23 e 54-55), che, in attesa dello studio dei corredi, consentono di inquadrare almeno parte delle sepolture all'epoca tardo-classica ed ellenistica; per le aree indagate nel 1982 e 1985 non vi sono invece dati circa la presenza di sepolture (o riduzioni) di epoca arcaica.

Nel complesso, le tombe messe in luce tra il 1981 e il 1985 occupano una fascia di terreno estesa per 25 m in senso NS e larga circa 75 m in senso EO; una tomba isolata venne inoltre scoperta circa 25 m a SO dell'area scavata nel 1981. La necropoli fu ricavata terrazzando un pendio naturale in leggera discesa verso NO, con le tombe posizionate su più livelli. Nel settore più occidentale, quello con maggiore interro al di sopra del banco roccioso, grazie alle sepolture ancora visibili è possibile constatare che le tombe furono rinvenute tra 70-80 cm e 1,5-2 m di profondità rispetto al piano di campagna. Nel settore occidentale le tombe sono tutte orientate in senso NO/SE, forse per la presenza di una strada con battuto in pietrame minuto di cui un breve tratto è stato individuato nel 2004 circa 10 m a NO delle sepolture. Questo tracciato, che correva tra il nucleo principale delle tombe individuate nel 1981 e le sepolture nn. 1-4 e 6, come documentato dagli scavi del 2020, potrebbe essere messo in relazione con la strada orientata NO/SE e documentata nel 1999 dalle prospezioni geofisiche, rimaste inedite, condotte dall'Università di Sidney (Robinson 2003; De Santis, Congedo 2010, 179-180). Almeno lungo il margine meridionale, il tracciato risulta bordato da una fila di pietre informi di medie dimensioni, ancora ben conservata all'altezza delle tombe nn. 7 e 9; l'allineamento su questo percorso anche delle tombe arcaiche conferma che esso risalga almeno al VI sec. a.C.

Procedendo verso E, infine, le tombe assumono invece un marcato orientamento NS o EO, come appare evidente nel settore scavato nel 1985; quest'area funeraria potrebbe essere stata condizionata, nel suo orientamento, dalla cd. *via Sallentina*, che doveva correre poco più a E, grossomodo ricalcata dall'odierna strada di Monte d'Elia (Uggeri 1983, 291-295, 298-300).

G.S.

4. Indagini preliminari allo scavo: dalla cartografia archeologica ai rilievi topografici e alle prospezioni geofisiche

La campagna di scavo archeologico del 2020 rappresenta il punto di arrivo di una serie di ricerche che hanno interessato il sito di Αλέτιον/*Aletium* a partire dal 2013, quando una prima convenzione operativa tra l'allora Istituto per i Beni Archeologici e Monumentali (IBAM) del CNR (oggi ISPC-CNR) e il Comune di Alezio pose le basi per un progetto di ricerca di ampio respiro che confluì nel 2016 nella pubblicazione della carta archeologica dell'abitato (Ferrari, Scardozzi 2016). L'obiettivo principale era quello di comporre un quadro complessivo delle presenze archeologiche, che potesse agevolare la lettura topografica e diacronica di tutti i ritrovamenti che, molto spesso occasionali, sono avvenuti a partire dalla seconda metà del Settecento, periodo a cui risale la nascita e lo sviluppo della moderna Alezio (all'epoca ancora denominata Villa Picciotti).

Questo lavoro ha riportato l'attenzione sull'area della necropoli di Monte d'Elia, che, sia pur parzialmente salvata dal degrado, nel corso degli anni aveva visto venir meno l'interesse scientifico, fermatosi ai dati parziali acquisiti dagli scavi del 1981-1985; in realtà, si è potuto constatare come anche la sola rilettura dei dati di scavo pubblicati necessitasse di una ricerca più approfondita e contestualizzata sulle sepolture e sui corredi, al fine di definire almeno le linee generali dell'evoluzione dell'area funeraria nel corso di oltre quattro secoli, dal VI al II sec. a.C. Riguardo l'aspetto epigrafico, inoltre, le ricerche per la carta archeologica di Alezio hanno consentito di portare a 56 i testi noti, di cui ben 13 proprio da Monte d'Elia: di queste epigrafi messapiche, tre sono ancora *in situ* (*IMA* 53, 54, 55), due risultano disperse (*IMA* 23, 24), una è custodita presso il Museo Civico di Gallipoli (*IMA* 28) e le restanti sette si trovano nel parco antistante il Museo Civico Messapico di Alezio (*IMA* 46, 47, 48, 49, 50, 51, 52).

Le ricerche per la carta archeologica hanno anche permesso di recuperare la documentazione grafica relativa agli scavi svolti nel 1981-1985 a Monte d'Elia, costituita essenzialmente da una planimetria di A. Duma e A. Zingariello, conservata nell'archivio della Soprintendenza per i Beni Archeologici della Puglia e relativa agli scavi del 1981-1982, e una planimetria disegnata da F. Danese nel 1987, conservata nell'archivio del Comune di Alezio, che riporta sia gli scavi del 1981-1982 – ma con alcune differenze rispetto alla precedente pianta – sia quelli del 1985 (Zezza 1991, fig. 2; D'Elia 2001, fig. 5). Essendo queste planimetrie incomplete, a volte incoerenti fra loro e tutte prive di georeferenziazione, è emersa da subito la necessità di disporre di una documentazione grafica aggiornata. Pertanto, nel 2017, nell'ambito delle attività di ricerca dell'allora Information Technologies Laboratory dell'ISPC-CNR (oggi Digital Heritage Innovation Laboratory), si è provveduto a effettuare un primo rilievo strumentale tramite laser scanner della porzione di necropoli riportata in luce, al fine di ottenere un elaborato tridimensionale metricamente preciso che andasse a documentare lo *status quo*.

L'interesse nello studio del sito, dapprima incentrato sulle ricerche passate, nel 2019 ha poi puntato nella direzione opposta, con la volontà di meglio comprendere le valenze scientifiche della necropoli: da questi presupposti, sono state quindi realizzate ulteriori e più organiche attività di ricerca che potessero porre le basi per la pianificazione di eventuali nuovi scavi archeologici, anche su impulso dell'Amministrazione Comunale di Alezio e grazie al coinvolgimento del Dipartimento di Beni Culturali dell'Università del Salento. La stipula nel 2019 del già ricordato accordo di collaborazione scientifica fra questi tre Enti ha portato alla programmazione di una serie di indagini multidisciplinari, finalizzate a integrare una nuova e più completa campagna di rilievo topografico con la documentazione del primo sottosuolo mediante prospezioni geofisiche. In primo luogo, il rilievo laser scanner del 2017 è stato integrato con un nuovo rilievo fotogrammetrico di tutta l'area del parco archeologico (circa 11.000 m^2) realizzato tramite l'ausilio di un drone, cui se ne è aggiunto uno ulteriore di dettaglio riguardante la porzione dei resti della necropoli posta al di sotto della tettoia. Sono inoltre state realizzate diverse sezioni utili a una migliore comprensione del rapporto di quota delle singole tombe e a documentare l'orografia del terreno, dati in questo caso completamente assenti nelle planimetrie degli anni Ottanta ed essenziali per un'organica lettura topografica della necropoli (Leucci *et al.* 2019, 3-7).

In collaborazione con l'Archaeological Mapping Laboratory dell'ISPC-CNR, i nuovi rilievi prodotti sono stati utilizzati per verificare e correggere le già citate planimetrie realizzate negli anni Ottanta del secolo scorso. A tal riguardo, va evidenziato che sono subito emerse evidenti incongruenze relativamente alla posizione, all'allineamento e anche al numero delle sepolture rispetto alle planimetrie di Duma-Zingariello e Danese, dovute in parte alle deformazioni di questa documentazione cartacea e ad alcune sue imprecisioni, in parte al fatto che i lavori di interro/sterro del 1989 e 2004, poco accurati, hanno determinato lievi spostamenti di alcune sepolture rispetto alla loro posizione originaria oppure hanno causato la completa distruzione di altre, in particolare di alcune tombe arcaiche strutturalmente più fragili. Nel complesso, la planimetria di Duma-Zingariello (che riporta anche la numerazione ufficiale delle tombe messe in luce nel 1981 e di parte di quelle del 1982) è risultata piuttosto fedele alla situazione reale e quindi è stata ritenuta più affidabile anche per le tombe non più in vista; quella di Danese, invece, è nel complesso meno precisa, ma costituisce l'unica documentazione disponibile per le tombe messe in luce nel 1985 nel settore orientale del Parco Archeologico e non più visibili. Nel 2019, si è così giunti all'elaborazione di una nuova planimetria, che corregge e integra le due precedenti e che è anche georeferenziata in relazione alla situazione attuale del sito (Leucci *et al.* 2019, 7-8, figg. 6-7).

A ulteriore supporto dei rilievi topografici e in vista della campagna di scavo del 2020, sono state effettuate anche prospezioni GPR da parte del Geophysics Laboratory dell'ISPC-CNR, con lo scopo di acquisire ulteriori informazioni sull'estensione della necropoli e la sua organizzazione. Nel complesso, utilizzando un georadar IDS Ris Hi Mod system, fornito di antenna dual band da 200-600 MHz, sono state indagate sette aree disposte a ridosso del settore della necropoli scavato nel 1981-1982 e ancora parzialmente in vista, collocate a N, a S e a E di esso, dove si sovrappongono parzialmente anche alle più orientali tra le aree oggetto di scavi archeologici nel 1982 (Leucci *et al.* 2019, 10-24, figg. 7-25). In totale, sono state evidenziate oltre una ventina di anomalie compatibili con possibili tombe simili a quelle messe in luce dagli scavi archeologici, oppure riferibili agli effetti prodotti dagli scavi stessi nel

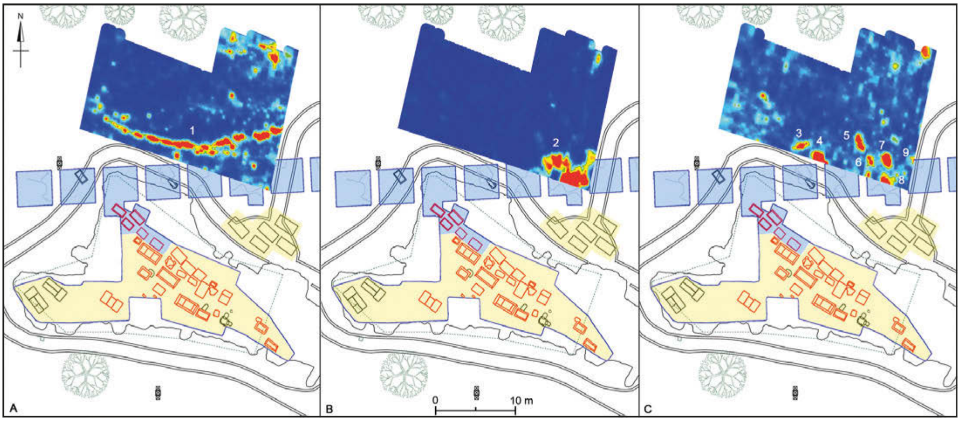

Fig. 3 – Time slices a differenti profondità (A: 70-93 cm; B: 122-145 cm; C: 156-180 cm) elaborate a partire dai profili georadar misurati con l'antenna da 600 MHz: sono indicate anomalie riferibili a una superficiale conduttura moderna (n. 1) e a sottostanti tombe e cavità prodotte dagli scavi del 1982, in parte riempite da materiale inerte (nn. 2-9).

caso che le sepolture sia state rimosse (tagli nel banco argilloso-calcareo per l'asportazione di casse o lastroni e riempimento delle cavità così prodotte con brecciolino), come dimostrato dai saggi di verifica effettuati nel 2020. Infatti, in questa occasione alcune delle aree indagate mediante prospezioni georadar sono state in parte oggetto di scavo archeologico, che in alcuni casi (come nel settore aperto subito a N dello scavo del 1981 e in corrispondenza di alcuni dei saggi del 1982) hanno mostrato una coerenza tra le anomalie (Fig. 3) e il dato archeologico (cfr. *infra* § 6), mentre in altri casi, come poco più a E o a S dello scavo del 1981, hanno evidenziato una mancata relazione tra dato geofisico ed evidenza antica, fenomeno che può trovare una spiegazione nella natura geologica del primissimo substrato o nella cattiva penetrazione del segnale elettromagnetico a causa della consistenza argillosa del terreno.

I.F., F.G., G.L., G.S.

5. Il nuovo rilievo topografico

5.1 *Il rilievo con laser scanner e mediante tecniche di fotogrammetria digitale*

Le operazioni di indagine archeologica del 2020 si sono basate sulle planimetrie del sito di Monte d'Elia redatte grazie ad attività di restituzione metrica delle evidenze condotte tra il 2017 e il 2019 (cfr. *supra* § 4), realizzate con tecniche di rilievo strumentale basate sia sui sensori attivi che passivi, mediante l'impiego combinato del laser scanner e di tecniche di fotogrammetria digitale di tipo Structure from Motion (SfM) (Gabellone *et al.* 2017).

Fig. 4 – Documentazione fotogrammetrica delle fasi di scavo stratigrafico del piccolo sarcofago denominato Tomba 2, messo in luce nel 2020.

Durante le fasi di scavo si è proceduto ad affiancare il rilievo diretto, e in alcuni casi a sostituirlo, con la realizzazione di modelli tridimensionali fotogrammetrici finalizzati a documentare le varie UU.SS.: operazione particolarmente rapida nell'esecuzione e altrettanto accurata nella resa metrica, che ha consentito di velocizzare non poco le operazioni di scavo.

Nel dettaglio, le elaborazioni 3D image-based sono state realizzate con una camera Sony Alpha 7 III R con obiettivo Canon EF 24 mm f/1.4L USM II e l'ausilio di un'asta telescopica e hanno riguardato alcuni saggi che per la loro complessità si sono rivelati particolarmente indicati. Sono quindi stati effettuati dei set di acquisizione fotografica con un overlap del 60-70%, e tramite Agisoft Metashape (v 1.6.1) è stata elaborata una serie di modelli digitali texturizzati, successivamente orientati, scalati e agganciati alla scansione

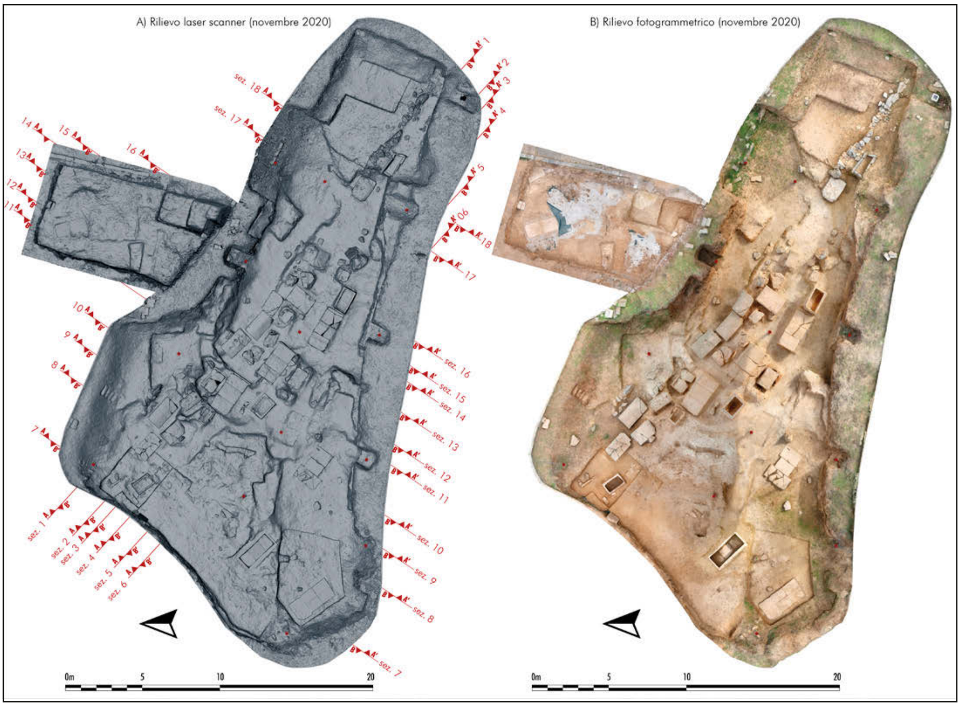

Fig. 5 – Rilievo generale di fine scavo: elaborazione laser scanner e fotogrammetrica a confronto.

laser di base attraverso dei GCPs (Ground Control Points). A partire da essi sono state elaborate tavole planimetriche e sezioni utili alla lettura diacronica delle fasi di scavo nei singoli saggi e alla comprensione dei rapporti di quota con le altre evidenze (Fig. 4). Al contempo, per redigere la planimetria generale dell'intera area di scavo, sono stati elaborati due ulteriori modelli perfettamente sovrapponibili e metricamente coerenti con i rilievi laser scanner, uno come documentazione finale del primo periodo di scavo (luglio-agosto) e l'altro al termine del secondo (ottobre-novembre), coincidente con la conclusione stessa delle indagini.

Le operazioni di rilievo sono state completate, come documentazione di fine scavo, con una scansione laser generale delle diverse aree indagate, utile sia a definire meglio lo stato di avanzamento delle indagini, sia a pianificare eventuali ulteriori campagne di scavo. Sono state effettuate 39 acquisizioni tramite un laser scanner Leica P20, garantendo una restituzione delle evidenze archeologiche con un'elevata accuratezza geometrica a partire da una maglia di acquisizione sub-centimetrica opportunamente definita in funzione delle superfici di riferimento. La fusione delle singole nuvole all'interno di un

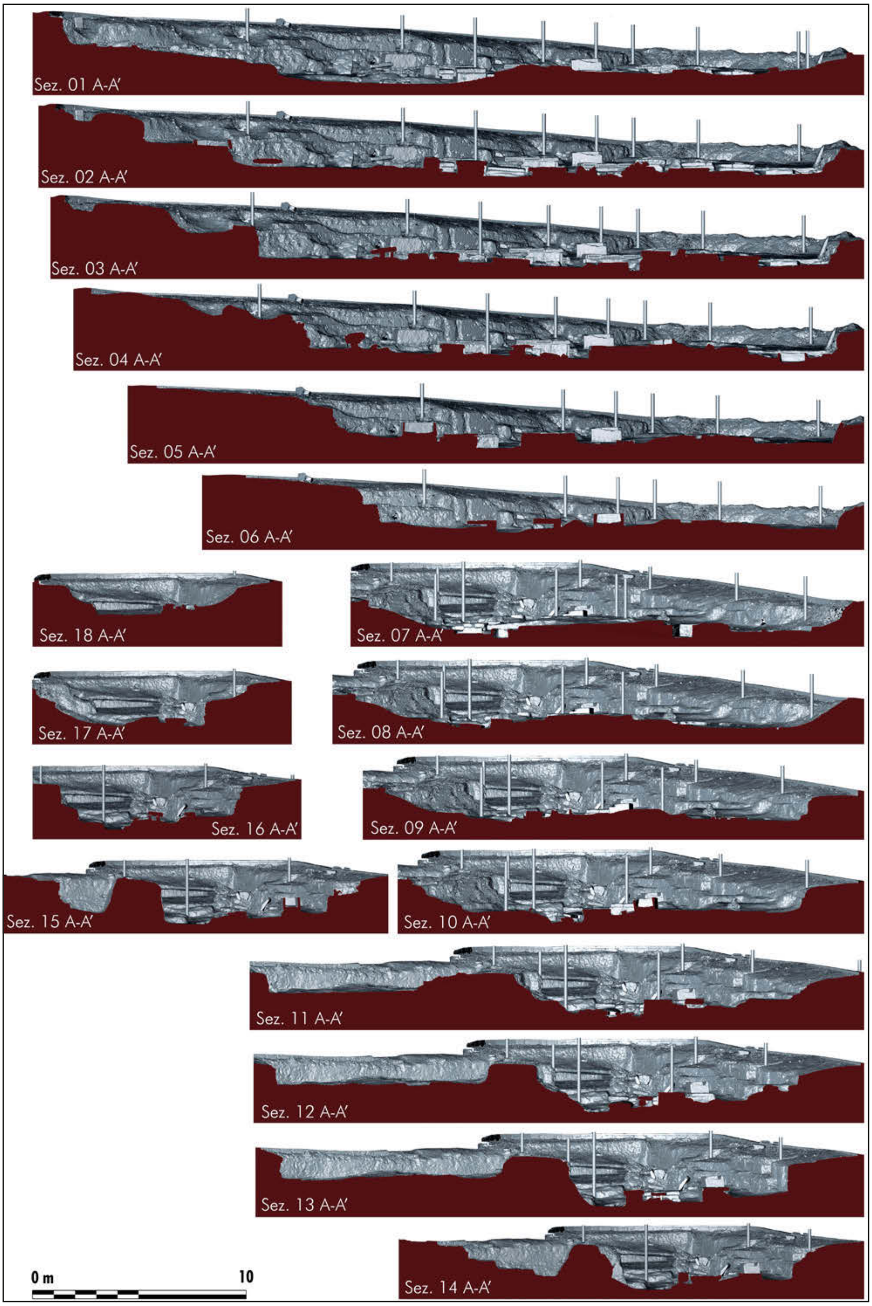

Fig. 6 – Sezioni A-A' realizzate sul modello 3D ottenuto dal rilievo con laser scanner.

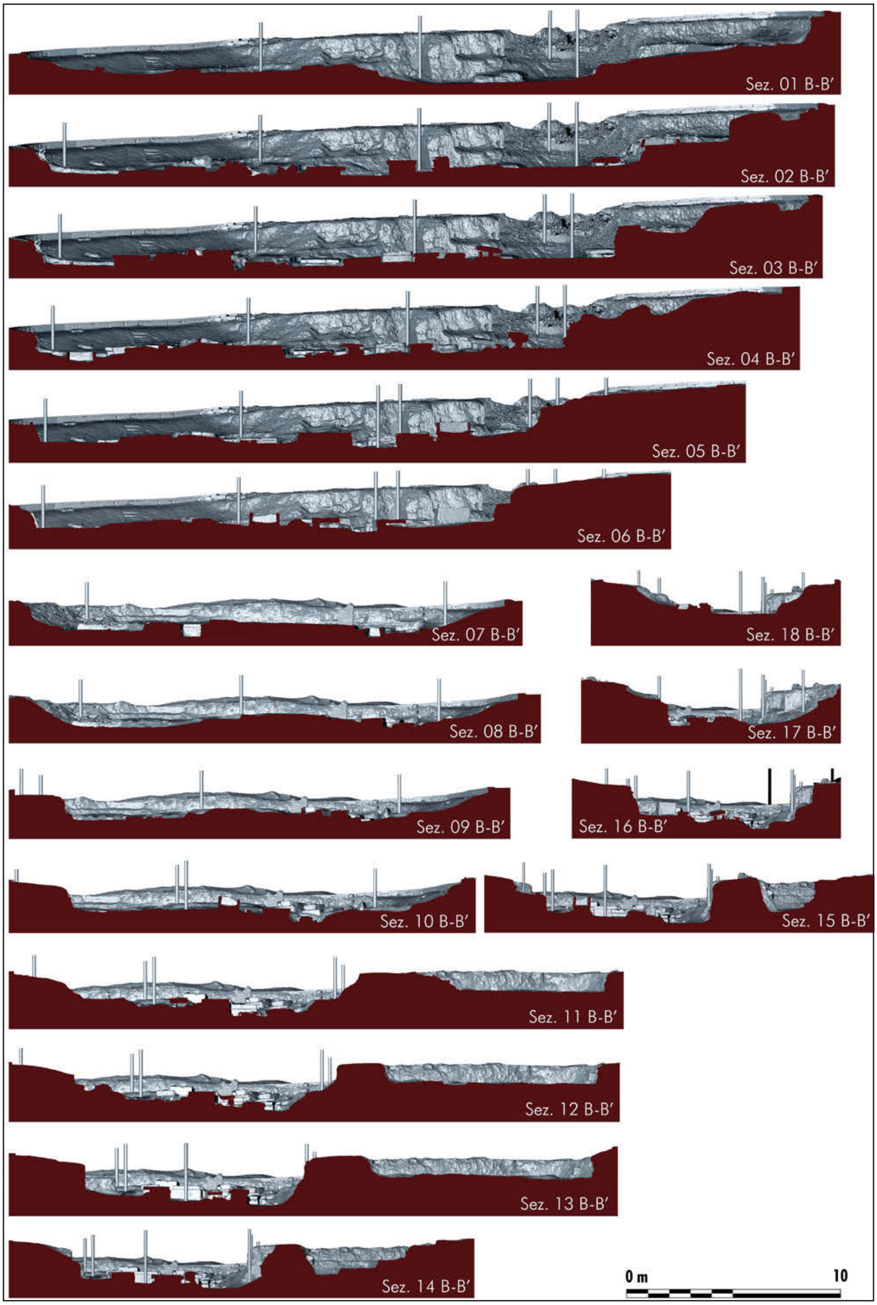

Fig. 7 – Sezioni B-B' realizzate sul modello 3D ottenuto dal rilievo con laser scanner.

unico file .pts di 247.546.300 punti (8,2 Gb) è stata effettuata manualmente in Cyclone (v 8.1.1) e successivamente ottimizzata e decimata in Geomagic (Studio 2003), per l'elaborazione di un modello poligonale in formato .obj (1,42 Gb), con un adeguato compromesso fra la qualità del dettaglio e la capacità di gestione dello stesso.

Il rigore metodologico e l'omogeneità dei dati prodotti dalla strumentazione laser e dai sistemi basati su algoritmi SfM hanno permesso il controllo dell'intera mole di informazioni all'interno del medesimo spazio di lavoro 3D, con modelli perfettamente sovrapposti e predisposti a fornire tutte le informazioni utili, sia geometriche che colorimetriche, molto più complete di quelle realizzabili con le tradizionali tecniche di rilievo diretto, con tempistiche decisamente inferiori e con un grado di accuratezza nettamente superiore. L'integrazione tra queste tecnologie dimostra come le caratteristiche dei singoli strumenti siano connotate da un livello di complementarità tale da renderle un sistema integrato più performante e flessibile, in grado di restituire un risultato decisamente migliore in termini assoluti e capace di adattarsi alle singole esigenze morfologiche dei diversi oggetti presenti nella scena rilevata. Il risultato raggiunto è quindi un modello digitale conoscitivo, ovvero un contenitore di informazioni interrogabile a vari livelli (Fig. 5).

A partire dai modelli 3D sono state poi elaborate sezioni planimetriche e verticali a quote differenti (Figg. 6-7). Il modello tridimensionale è facilmente misurabile, per cui risulta immediato il calcolo delle superfici, dei volumi e dei dati metrici di ogni elemento investigato. Quanto realizzato, ovvero una restituzione correlata a un preciso momento, rappresenta la base di partenza per qualsiasi futura azione di indagine e monitoraggio. La sovrapposizione dei rilievi eseguiti in date successive consentirà infatti la lettura grafica e analitica degli eventi temporali intercorsi. In particolare, sarà possibile eseguire e ripetere tali misurazioni sia sul piano bidimensionale (confronto tra sezioni orizzontali e profili verticali), sia sul piano tridimensionale (confronto tra superfici e mappatura degli interventi di scavo) per le necessarie valutazioni metriche.

I.F., F.G.

5.2 *La definizione e il posizionamento delle aree di scavo del 1981-1985*

I rilievi 3D eseguiti durante la campagna di scavo del 2020 e al termine della stessa sono stati anche utilizzati per affinare ulteriormente la georeferenziazione della planimetria che integra i rilievi delle aree scavate nel 1981-1985 realizzati da Duma-Zingariello e Danese (Fig. 2). Infatti, il nuovo ampliamento a N ha permesso di individuare le tombe 2/82 e 3/82 (Fig. 8), rinterrate dopo lo scavo del 1982, consentendo così di posizionare con una buona approssimazione anche le altre tombe messe in luce nello stesso anno sia più a O che più a E. Lo stesso saggio ha probabilmente portato

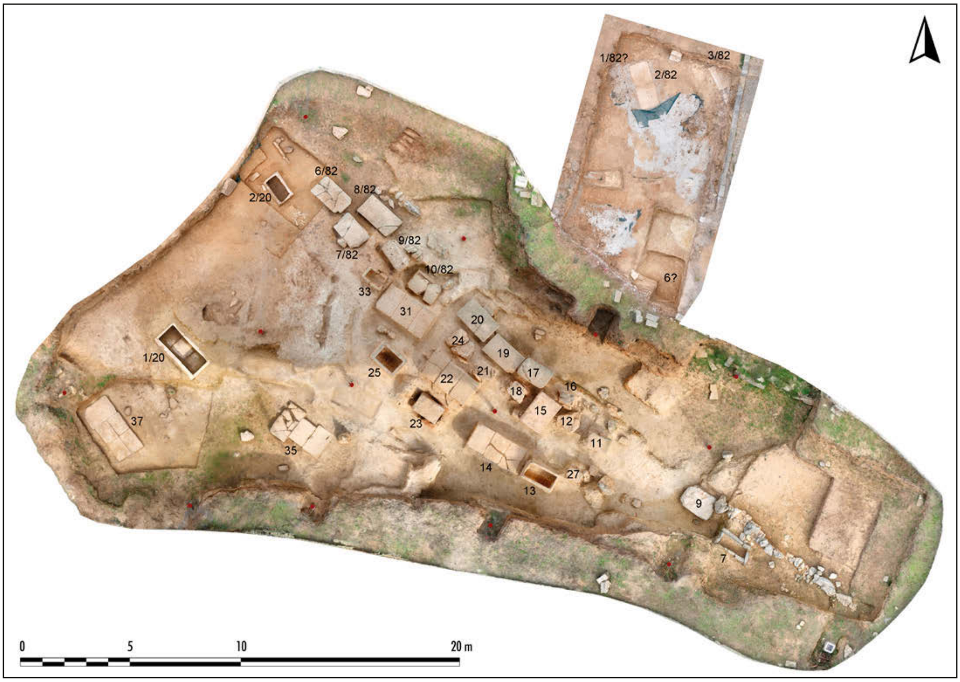

Fig. 8 – Rilievo fotogrammetrico del settore attualmente visibile della necropoli, con indicate le tombe messe in luce nel 1981-1982 e nel 2020.

all'individuazione dell'alloggiamento della tomba 1/82, subito a O della 2/82, e, più a S, anche quello della tomba 6, scoperta nel 1981 e rimossa per essere collocata nel giardino del Museo Archeologico di Alezio. Inoltre, delle nuove tombe messe in luce, la 2/20 – un piccolo sarcofago posto all'estremità nord-orientale dell'area indagata, che presenta un orientamento coerente con le sepolture vicine (come 6/82 e 7/82) – viene a trovarsi tra due quadrati esplorati nel 1982, quando probabilmente non venne individuato, mentre, più a S, si affianca alle tombe 36 e 37, messe in luce nel 1981, la tomba 1/20, presentando dimensioni simili e analogo orientamento; quest'ultima struttura è costituita da un grande ossario destinato ad accogliere la riduzione di sepolture preesistenti, riferibili a nove adulti e due bambini, a cui erano associati oggetti di corredo databili tra IV e seconda metà del II sec. a.C. (Mastronuzzi, Melissano 2021, 327).

Resta infine incerta l'ubicazione delle tombe messe in luce nel 1985, poste più a E e documentate solo dalla planimetria di Danese, le quali, rispetto a quanto precedentemente ipotizzato (Leucci *et al.* 2019, fig. 7), vanno probabilmente collocate poco più a O (Fig. 9). In questo caso, solo saggi di scavo e

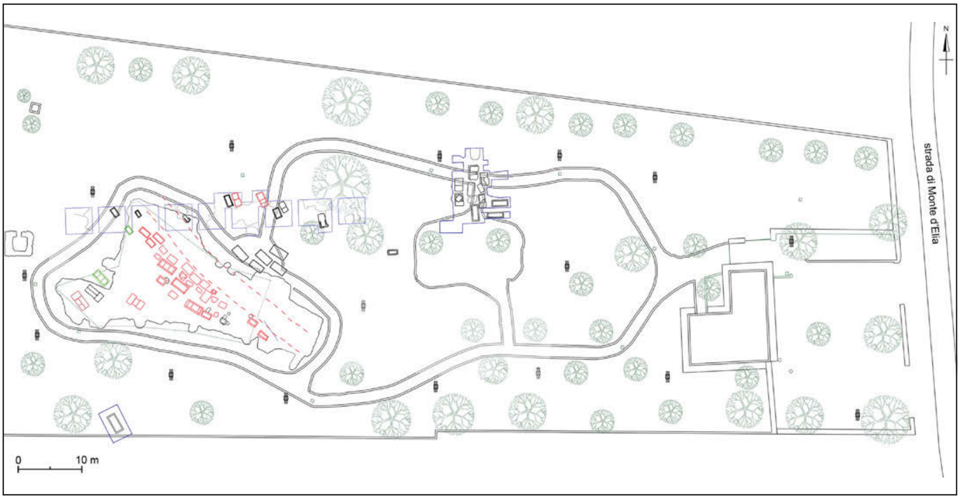

Fig. 9 – Planimetria generale del Parco Archeologico di Monte d'Elia con posizionamento delle varie aree di scavo (1981-1982, 1985, 2020): in rosso sono indicate le tombe ancora visibili, in verde quelle individuate nel 2020, in nero quelle non più visibili.

nuove prospezioni geofisiche potrebbero fare chiarezza sull'esatta posizione di questo nucleo della necropoli.

G.S.

6. Considerazioni conclusive

I rilievi topografici eseguiti, integrando tecniche diverse, nel 2017 e nel 2020 hanno permesso di sfruttare al meglio il valore informativo delle planimetrie realizzate a seguito degli scavi del 1981-1985, le quali, in attesa di indagini più estensive, costituiscono ancora una documentazione fondamentale per la ricostruzione dell'organizzazione e dell'estensione della necropoli messapica di Monte d'Elia.

La restituzione metrica dell'intera area di scavo, realizzata al termine delle indagini, è stata l'atto conclusivo di ulteriori rilievi indiretti di dettaglio che hanno affiancato o sostituito i rilievi diretti durante lo scavo stratigrafico, facilitando una rapida ripresa delle indagini e restituendo elaborati tridimensionali dall'immediato riscontro fra la geometria e il dato colore, facilmente leggibili e interrogabili. I risultati conseguiti confermano quindi la validità di un approccio basato su tecniche integrate di rilievo indiretto per una lettura multiscala, aperta a future implementazioni.

È risultata poi molto importante la verifica stratigrafica di alcune delle anomalie documentate dalle indagini geofisiche, che consente una rilettura

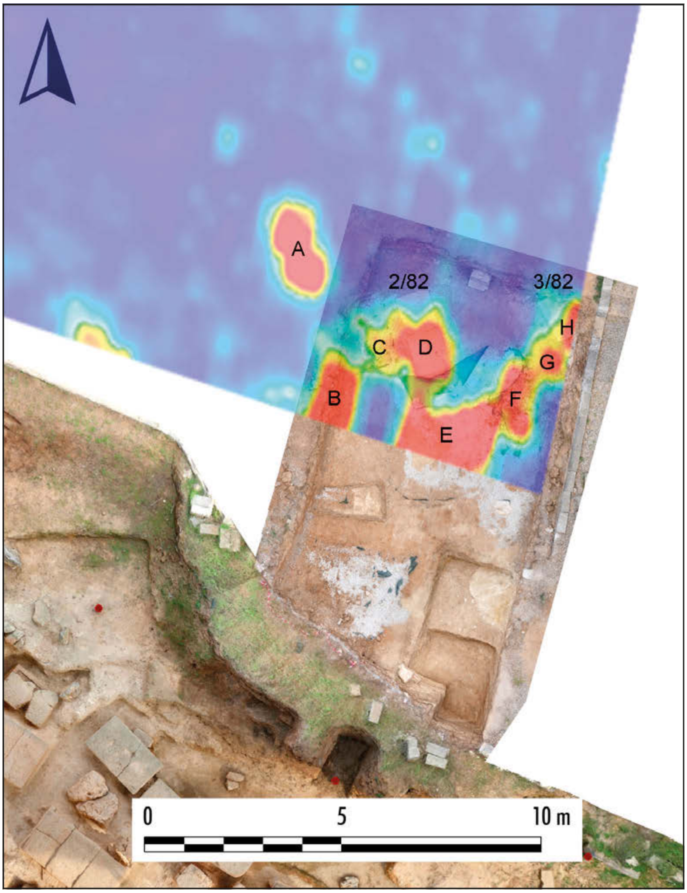

Fig. 10 – Rilievo fotogrammetrico dell'ampliamento dello scavo in direzione N, su cui è georeferenziata in trasparenza la time slice alla profondità di 139-163 cm ottenuta dai profili georadar misurati dall'antenna a 600 MHz.

delle misurazioni GPR basata sulle risultanze dello scavo; questo ha infatti evidenziato come parte delle anomalie sia da ricondurre a fenomeni naturali, mentre si è riscontrata una certa corrispondenza tra dato geofisico ed evidenza archeologica nell'area posta subito a N di quella indagata nel 1981. Qui, infatti, uno dei saggi eseguiti nel 2020 ha interessato parte della superficie indagata mediante georadar, documentando, a profondità comprese tra 1 e 1,15 m, quanto evidenziato dalle time slices comprese all'incirca tra -1,20 e -1,80 m, suggerendo anche una lieve rettifica della velocità di propagazione dell'onda elettromagnetica, da cui si calcola la profondità (in metri) delle anomalie, che era stata determinata in 0,09 m/ns (Leucci *et al.* 2019, 11) e che invece potrebbe essere leggermente inferiore. In particolare, due anomalie (Fig. 10, D e H) corrispondono alle tombe 2/82 e 3/82, una (C) al possibile sito della tomba 1/82, e altre tre (E, F, G) al riempimento con brecciolino di saggi di scavo del 1982; incerta è invece l'anomalia B, forse legata a fattori naturali, mentre l'anomalia A, posta al di fuori dell'area scavata, per orientamento, dimensioni e risposta elettromagnetica potrebbe corrispondere a un'ulteriore tomba.

In conclusione, le prospettive di ricerca prevedono, sempre a integrazione delle attività di indagine stratigrafica, un riesame della documentazione geofisica già acquisita, un'estensione delle prospezioni con l'impiego di nuova strumentazione e l'applicazione di differenti metodi geognostici, che permettano di indirizzare in maniera più efficace i saggi di scavo e contribuiscano a chiarire l'esatta ubicazione dell'area indagata nel 1985 e di conseguenza ad accertare l'estensione verso E della necropoli.

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BIBLIOGRAFIA

Andreassi G. 1986, *L'attività archeologica in Puglia*, in *Atti del Convegno di Studi sulla Magna Grecia*, XXV, Taranto, ISAMG, 371-396.

Ciongoli G.P. 1990, *Alezio*, in F. D'Andria, *Archeologia dei Messapi*, Bari, Edipuglia, 197-200.

D'Andria F. 1991, *Insediamenti e territorio: l'età storica*, in *Atti del Convegno di Studi sulla Magna Grecia*, XXX, Taranto, ISAMG, 393-478.

De Juliis E.M. 1982, *L'attività archeologica in Puglia*, in *Atti del Convegno di Studi sulla Magna Grecia*, XXI, Taranto, ISAMG, 293-322.

De Juliis E.M. 1983, *L'attività archeologica in Puglia*, in *Atti del Convegno di Studi sulla Magna Grecia*, XXII, Taranto, ISAMG, 503-530.

De Juliis E.M. 1984, *L'attività archeologica in Puglia*, in *Atti del Convegno di Studi sulla Magna Grecia*, XXIII, Taranto, ISAMG, 421-446.

De Juliis E.M. 1985, *Un quindicennio di ricerche archeologiche in Puglia: 1970-1984. Parte II: 1978-84*, «Taras», 5, 2, 177-227.

D'Elia G. 2001, *Alezio - Archeologia e storia di un comune del Salento*, Alezio, Tipografia Corsano.

De Mitri C. 2020, *Il settore centrale dell'arco ionio-salentino in età preromana (VIII-I sec. a.C.): nuovi dati ceramici da Alezio e Nardò*, «Fasti On Line», 479, 1-18 (http://www.fastionline.org/docs/FOLDER-it-2020-479.pdf).

De Pascalis A.L. 2000-2001, *Storia dei rinvenimenti archeologici di Alezio. Carta archeologica dell'area urbana*, Tesi di Laurea, Università di Lecce.

De Santis V., Congedo F. 2010, *Alezio (Lecce). F. 214 III SO I.G.M.*, «Notiziario delle Attività di Tutela, gennaio 2004 - dicembre 2005», n.s. I, 1-2, 179-182.

De Simone C., Marchesini S. 2002 (eds.), *Monumenta Linguae Messapicae*, I-II, Wiesbaden, Dr. Ludwig Reichert Verlag.

Ferrari I., Scardozzi G. 2016, *Contributo alla Carta Archeologica di Alezio*, Monografie dell'Istituto per i Beni Archeologici e Monumentali - C.N.R., 10, Bari, Scirocco Editore.

Gabellone F., Ferrari I., Giuri F., Chiffi M. 2017, *3D technologies for a critical reading and philological presentation of ancient contexts*, in Garagnani, Gaucci 2017, 591-595 (https://doi.org/10.19282/AC.28.2.2017.50).

Lamboley J.L. 1996, *Recherches sur les Messapiens IV-II siècle avant J.-C.*, Rome, École Française de Rome.

Leucci G., De Giorgi L., Ditaranto I., Giuri F., Ferrari I., Scardozzi G. 2019, *New data on the Messapian necropolis of Monte D'Elia in Alezio (Apulia, Italy) from topographical and geophysical surveys*, «Sensors», 19, 3494, 1-26 (https://doi.org/10.3390/s19163494).

Lombardo M. 1992, *I Messapi e la Messapia nelle fonti letterarie greche e latine*, Galatina, Congedo Editore.

Lombardo M. 1994, *Tombe, necropoli e riti funerari in Messapia: evidenze e problemi*, «Studi di Antichità», 7, 25-45.

Mastronuzzi G. 2011, *La tomba del Giardino Faccenna ed altri contesti arcaici di Vaste, in Messapia*, «Fasti On Line», 235, 1-22 (http://www.fastionline.org/docs/FOLDER-it-2011-235.pdf).

Mastronuzzi G., Melissano V. 2021, *Insediamenti e territorio nella Puglia meridionale in età romana*, «Thiasos», 10, 1, 321-349.

Pagliara C. 1983, *Materiali iscritti arcaici del Salento*, «Annali della Scuola Normale di Pisa», 13, 1, 1-99.

Robinson E.G.D. 2003, *Recent Australian and New Zeland field work in the Mediterranean Region. Field survey at Alezio, 2001*, «Mediterranean Archaeology», 16, 149-170.

Santoro C. 1981, *Osservazioni preliminari sui nuovi documenti epigrafici prelatini*, «Lingua e Storia in Puglia», 12, 33-80.

Santoro C. 1983, *Le epigrafi di Alezio e i problemi della lingua messapica*, in *Atti dell'VIII Convegno dei Comuni Messapici, Peuceti e Dauni (Alezio 1981)*, Bari, Grafica Bigiemme, 59-113.

Santoro C. 1984, *Nuovi studi Messapici III, primo supplemento*, Galatina, Congedo Editore.

Santoro C. 1986, *Alezio*, «Studi Etruschi», 52, 352-370.

Santoro C. 1991, *Alezio*, «Studi Etruschi», 56, 411-417.

Semeraro G. 1997, ἐν νηυσί*: ceramica greca e società nel Salento arcaico*, Bari, Edipuglia.

Uggeri G. 1975, *La viabilità preromana della Messapia*, «Ricerche e Studi - Brindisi», 8, 75-104.

Uggeri G. 1983, *La viabilità romana nel Salento*, Fasano, Grafischena.

Zezza G.M. 1991, *Alezio: continuità di vita in un centro antico del Salento*, Martina Franca, Arti Grafiche Pugliesi.

ABSTRACT

The Messapian necropolis of Monte D'Elia (used from the 6th to the 2nd cent. BC) is about 300 m S of the modern town of Alezio (Lecce, Apulia), which lays on one of the most important ancient settlements of the Salento peninsula (ancient Messapia). The site was investigated between 1981 and 1985 by the Apulian Archaeological Superintendence. In 2020, archaeological investigations have been resumed by the Department of Cultural Heritage of the University of Salento, with the participation of researchers from the Institute of Heritage Science of the National Research Council. Their research activities focused on geophysical prospecting and topographical surveys, performed thanks to the combined use of laser scanner and digital photogrammetry by drone. This contribution illustrates these research activities, which are aimed at understanding the general plan of the necropolis, through the integration of the information published in the 1980s with data from new investigations and surveys, and, more generally, at the reconstruction of its topographic organization and extension.

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LE CAVE ANTICHE DI PORTO MIGGIANO (SANTA CESAREA, LECCE): ANALISI METROLOGICA E RILIEVO TOPOGRAFICO DEI SETTORI ESTRATTIVI

1. Introduzione

Nell'ambito delle attività di ricerca che da alcuni anni l'Istituto di Scienze del Patrimonio Culturale (ISPC) del CNR sta svolgendo presso l'*Athenaion* di Castro, in provincia di Lecce (D'Andria *et al.* 2023), è stato sviluppato un progetto di ricerca finalizzato all'individuazione delle antiche cave di materiali lapidei che possono aver rifornito i grandi cantieri pubblici di questo centro (come le fortificazioni), dove si registra un largo impiego della calcarenite, e le maestranze attive nella realizzazione degli elementi architettonici e scultorei del Santuario di Atena, nei quali è largamente utilizzata anche la pietra leccese (Scardozzi 2023). Le indagini comprendono sia ricognizioni volte a documentare le cave antiche del territorio, sia analisi archeometriche dei materiali archeologici e dei siti estrattivi, ancora in corso, al fine di una caratterizzazione minero-petrografica e geochimica dei litotipi e di una determinazione delle provenienze dei blocchi e degli altri manufatti archeologici rinvenuti a Castro[1].

Gli scavi condotti nel settore sud-orientale del centro storico di Castro, prima in località Muraglie (Fig. 1A, n. 4; Fig. 1C) e poi in località Capanne (Fig. 1A, n. 3; Fig. 1D), hanno messo in luce un sistema di cinte murarie in blocchi parallelepipedi di calcarenite, posti in opera a secco, databile tra IV e II sec. a.C. e connesso prima con il soprastante *Athenaion* e successivamente con la trasformazione del sito in *castrum* (D'Andria 2009, 13-35, 2020, 79-91; De Mitri 2009; Mastronuzzi 2015). Le indagini stratigrafiche hanno infatti permesso di identificare tre fasi costruttive (D'Andria 2020, 82-88, 98-103), la più antica delle quali, riferibile alla seconda metà del IV sec. a.C.,

[1] Sono particolarmente grato a Francesco D'Andria per avermi coinvolto nelle ricerche su Castro da lui dirette, affidandomi lo studio delle aree estrattive del territorio e delle questioni connesse all'approvvigionamento dei materiali lapidei utilizzati per le cinte ellenistiche e, in generale, per la realizzazione dei manufatti archeologici in pietra calcarea rinvenuti nel sito. Le ricognizioni sono condotte da chi scrive e vedono la collaborazione di I. Ditaranto, F. Fortinguerra, P. Merola e I. Miccoli dell'Archaeological Mapping Laboratory della sede ISPC-CNR di Lecce. Le analisi archeometriche sono invece condotte dall'Heritage Materials Science Laboratory della sede ISPC-CNR di Firenze, con il coordinamento di E. Cantisani e la collaborazione di S. Vettori; queste indagini sono realizzate, oltre che su tutte le cave documentate, anche su campioni prelevati da blocchi in calcarenite delle tre cinte ellenistiche (sia nelle località Capanne e Muraglie, sia nello scavo di piazza Perotti e nel settore nord-occidentale del circuito) e dell'altare del santuario (per il quale, D'Andria 2020, 103-104), oltre che su manufatti in pietra leccese, tra cui i grandi fregi a girali rinvenuti sempre nell'area dell'*Athenaion* (per i quali, Ismaelli 2020).

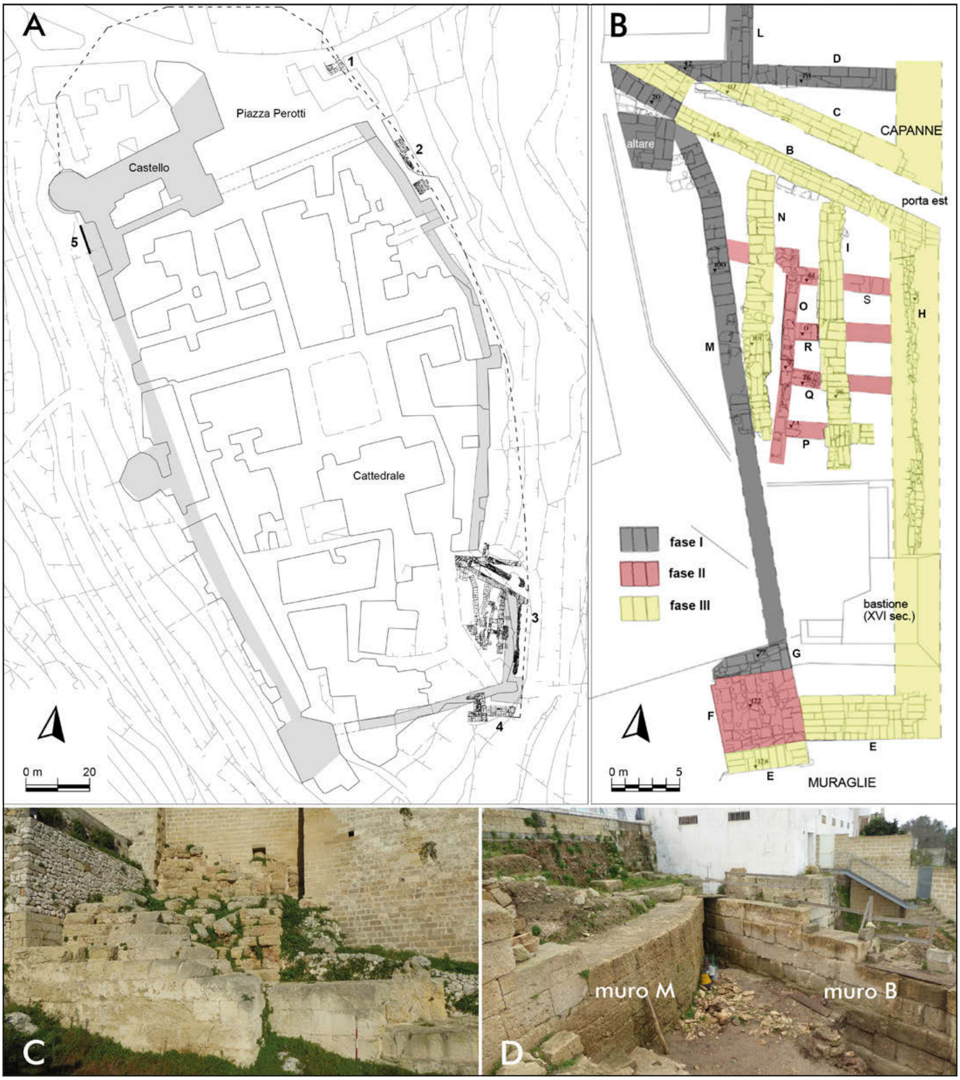

Fig. 1 – Castro: A) pianta generale dell'abitato moderno con indicazione delle fortificazioni cinquecentesche (in grigio chiaro) e dei tratti delle mura ellenistiche visibili o messi in luce (1-5); B) planimetria di dettaglio degli scavi nelle località Capanne e Muraglie con indicazione delle fasi costruttive (rielab. da D'Andria 2020, figg. 2 e 3); C) tratti murari messi in luce in loc. Muraglie con in primo piano la terza fase; D) i tratti murari M e B in loc. Capanne.

consiste in una struttura che svolgeva contemporaneamente funzioni di difesa e di terrazzamento dell'area in cui sorgevano il tempio e l'altare (Fig. 1B, muri G, M e D). Realizzata con blocchi di una calcarenite piuttosto compatta di colore giallastro, in alcuni casi fortemente conchiglifera, generalmente lunghi tra 1,49 e 1,56 m, larghi 70 cm e alti 42-46 cm, questa prima cinta poteva avere una lunghezza di oltre 600 m e racchiudere una superficie di ca. 2 ettari (Fig. 1A). In località Capanne, in corrispondenza di uno sfalsamento, vi si apriva una porta, mentre un'altra doveva trovarsi all'estremità settentrionale del circuito, a N di piazza Perotti.

La seconda fase, datata alla prima metà del III sec. a.C. (Fig. 1B, muri F, O, P, Q, R, S), consiste in un ampliamento che sembrerebbe interessare solo l'angolo sud-orientale della cinta preesistente, a S della porta di località Capanne, che in questo periodo assume una struttura a tenaglia. Per la sua realizzazione vengono utilizzati blocchi di una calcarenite diversa rispetto a quella della fase precedente, sempre giallastra ma meno compatta; i conci sono anche meno lunghi (generalmente tra 1,18 e 1,20 m), più larghi (78-81 cm) e più alti (51 cm). Infine, la terza fase (Fig. 1B, muri L, B, C, E, H), riferita alla prima metà del II sec. a.C., quindi successiva alla conquista romana e al cambiamento di funzione del sito, corrisponde a un radicale intervento di ricostruzione delle mura. Come documentano i resti visibili nello scavo di piazza Perotti (Fig. 1A, n. 1; Lippolis, Mazzario 1981; Galati 2015b; D'Andria 2020, 91), quelli messi in luce nel tratto nord-orientale del circuito (Fig. 1A, n. 2; Galati 2015a) e i blocchi inglobati alla base del lato occidentale del Castello Aragonese (Fig. 1A, n. 5), tale intervento sembra interessare tutto il perimetro murario; la nuova fortificazione ingloba e riveste le precedenti, determinando un ulteriore ampliamento del terrazzo nella zona a S della porta di località Capanne, che assume ora una particolare struttura a corridoio molto stretto (lungh. ca. 20 m, largh. 2,20 m). In questa fase i blocchi, messi in opera con regolarità in filari alternati di testa e per lungo, sono più stretti (largh. 50-53 cm) e più allungati (lungh. 1,58-1,62 cm) rispetto alle fasi precedenti, con altezze variabili tra 45 e 55 cm; la calcarenite utilizzata è simile a quella della seconda fase, ma più compatta e con una granulometria più fine.

I cantieri che si susseguirono nel corso di circa due secoli per la realizzazione di questi circuiti murari dovettero richiedere uno sforzo costruttivo molto elevato, in particolare per l'approvvigionamento di un consistente quantitativo di materiale lapideo; inoltre, le differenze visibili a livello macroscopico tra i tipi di calcarenite utilizzati nelle tre fasi edilizie sembrano suggerire la provenienza dei blocchi da altrettanti siti estrattivi, che dovevano tutti trovarsi a una certa distanza da Castro. Infatti, il promontorio su cui sorge il centro è costituito da calcari dell'Oligocene superiore (cd. Calcari di Castro: Largaiolli *et al.* 1969, 13, 19-21, 49; Martinis 1970, 13, 18-20, 49; Ricchetti, Ciaranfi 2013, 38-39; per l'inquadramento dell'area, Bossio *et al.* 2005 e la *Carta Geologica d'Italia* in scala 1:100.000 e 1:50.000), molto duri e compatti, di colore biancastro o grigio chiaro, che risultano difficilmente lavorabili, mentre non sono presenti le calcareniti, molto più tenere e da cui si possono ottenere blocchi; queste, spesso impropriamente definite "tufo", affiorano solo in corrispondenza dell'area di Castro Marina, alle pendici sud-occidentali del promontorio, presso l'insenatura del porto, oppure qualche chilometro più a NO, tra i moderni centri di Vignacastrisi, Diso, Ortelle e Spongano, o lungo la costa a NE e SE di Castro.

Queste calcareniti, costituite da diverse varietà formatisi nel Pliocene e nel Pleistocene, sono denominate Calcareniti del Salento nella vecchia bibliografia geologica (Largaiolli *et al.* 1969, 13, 32-35, 50-51; Martinis 1970, 13, 24-26, 49-51), mentre in quella più recente (Ricchetti, Ciaranfi 2013, 53-55, 86, tav. II) sono declinate in diversi litotipi (Sistema di Miggiano, Calcarenite di Gravina e Formazione di Uggiano la Chiesa). Molti di questi affioramenti, soprattutto quelli lungo la costa tra Santa Cesarea Terme e Marina Serra, ma anche alcuni di quelli all'interno, sono stati oggetto di estrazione antica, oltre che in epoca moderna (Scardozzi 2023). Tra essi spicca sicuramente il sito estrattivo di Porto Miggiano, che, oltre a essere tra i più estesi, conserva ancora un'ampia porzione del nucleo originario, solo parzialmente intaccato da attività di coltivazione più recente; per queste ragioni esso è stato oggetto di un'indagine molto dettagliata, che ha compreso la documentazione e il rilievo integrale (eseguito sia con la cd. fotogrammetria da drone che con laser scanner da terra) al fine di definirne estensione, cronologia, tecniche e fasi di estrazione, modalità di movimentazione e trasporto dei blocchi.

2. L'area estrattiva e le caratteristiche metrologiche dei vari settori

Il sito estrattivo di Porto Miggiano si trova circa 4,5 km a NE di Castro (Fig. 2A) e interessa un deposito calcarenitico del Pleistocene appartenente al cd. Sistema di Miggiano (Zezza, Bruno 1991; Tropeano *et al.* 2004; Bossio *et al.* 2005, 53-55; Ricchetti, Ciaranfi 2013, 56-58, 86). Esso comprende tre cave costiere, ancora bene identificabili nonostante l'aggressione prodotta negli ultimi anni dalla realizzazione di installazioni e strutture turistiche: una, presso l'omonima insenatura (Fig. 2B, n. 1), presenta evidenti tracce di coltivazione riferibili, in base alla metrologia dei blocchi cavati (alt. 23-27 cm, lungh. 45 cm, largh. 35 cm), a epoca basso-medievale o moderna, mentre le altre due, più vicine alla torre cinquecentesca (Fig. 2B, nn. 2-3), conservano ancora settori estrattivi che, stando alle dimensioni dei conci distaccati, sono certamente più antichi. Su queste ultime si sono quindi concentrate le attività di ricerca e rilievo, finalizzate, come nei più recenti lavori su cave costiere

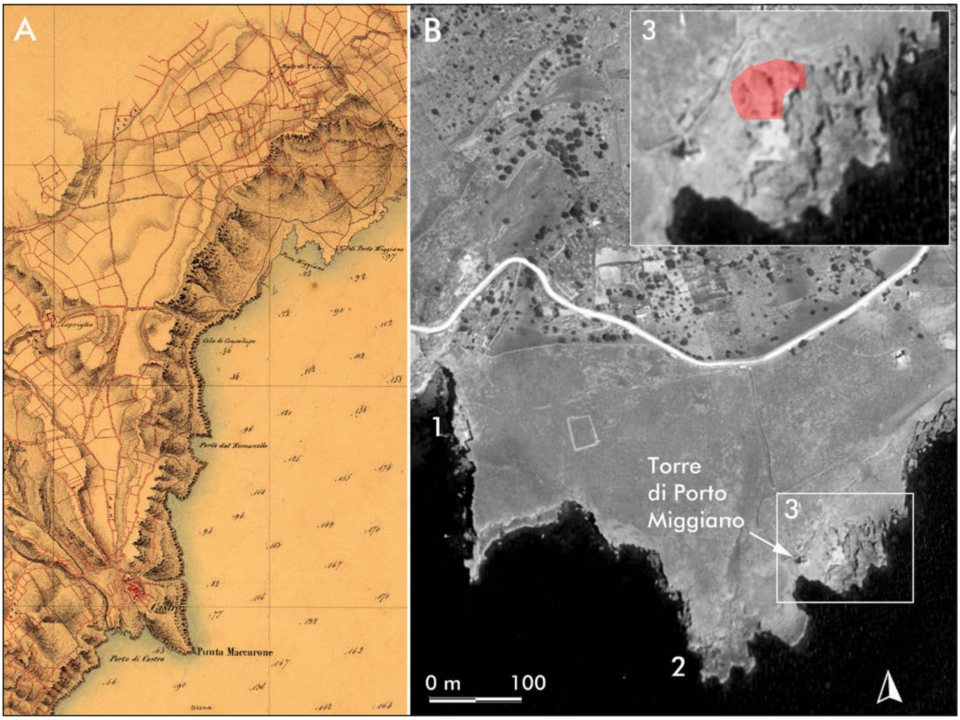

Fig. 2 – A) particolare del Foglio n. 42 della *Carta dei rilievi delle coste dell'Adriatico dal Fiume Tronto a Gagliano del Capo di S.ta Maria di Leuca* (1830-1835, scala dell'originale 1:20.000), in cui compare il tratto di costa tra il Porto di Castro e Porto Miggiano. B) Particolare di una foto aerea IGM del maggio 1943 (F. 215, strisciata 2, fotogramma 25) in cui sono indicate le cave e, nel riquadro, è evidenziata la superficie oggi interrata di quella posta presso la torre cinquecentesca (entrambi i documenti sono conservati all'Archivio IGM di Firenze).

di arenarie e calcareniti (Previato 2016; Buscemi Felici, Felici, Lanteri 2020), a indagare gli aspetti legati alle tecniche estrattive, gli strumenti utilizzati e il trasporto del materiale.

La cava principale, estesa su una superficie di circa 0,4 ettari, si trova subito a E della torre (Fig. 2B, n. 3; Fig. 3), a ca. 7-8 m s.l.m. e a ridosso della linea di costa (cenni in Belotti 1997, figg. 11 e 14; Guaitoli 1997, figg. 16-17; Auriemma 2004, I, 261-262; D'Andria 2009, 19; Calia *et al.* 2011, 269-270; Margiotta, Sansò 2017, 473-474; D'Andria 2020, 82). Coltivata a cielo aperto, è del tipo a fossa, con fronti, alti fino a 4,90-5,50 m, lavorati anche a gradoni, che presentano ben visibili i segni lasciati dagli strumenti utilizzati per tagliare la roccia ed estrarre i blocchi. Le tecniche documentabili sono coerenti con la procedura standard per il distacco mediante tagliata perimetrale, realizzata con un piccone, e scalzamento alla base

Fig. 3 – Porto Miggiano: veduta aerea da drone, scattata da O, della cava principale; nel riquadro, fasi di rilievo con laser scanner.

ottenuto con cunei metallici; in alcuni casi è evidente come l'estrazione sia avvenuta per letti di cava, ossia con il distacco dei blocchi ottenuto agendo, anche semplicemente con la punta del piccone (cd. tecnica à *pointillé*), sui naturali piani di sedimentazione della roccia.

La lettura delle tracce in negativo sulle pareti dei fronti di cava e i piani di distacco, oltre che su alcuni blocchi semi-cavati e abbandonati, ha consentito di identificare quattro aree estrattive corrispondenti ad almeno cinque fasi di coltivazione. Stando alle risultanze metrologiche, la più antica (ed estesa) interessa tutto il settore centrale della cava (Fig. 4A) e si caratterizza per l'estrazione di blocchi alti fino a 50-55 cm, lunghi 1,20-1,65 m e spessi 45-55 cm (Fig. 5A), sicuramente compatibili con quelli della terza fase della cinta muraria di Castro, a cui rimanda anche, in attesa dei risultati delle analisi archeometriche, l'aspetto macroscopico della pietra, di colore giallastro chiaro e con una granulometria piuttosto fine. A tal proposito, va evidenziato che Castro costituisce il centro antico più vicino, facilmente raggiungibile via mare, e che una connessione tra la cava di Porto Miggiano e i cantieri ellenistici di Castro fosse stata già ipotizzata in passato (D'Andria 2009, 19; D'Andria 2020, 82, nota 8; per lo sfruttamento del sito estrattivo in epoca ellenistica, inoltre Belotti 1997, fig. 11).

Che l'estrazione sia avvenuta in funzione di un trasporto via mare dei blocchi è documentato da almeno tre punti in cui dalla cava è possibile

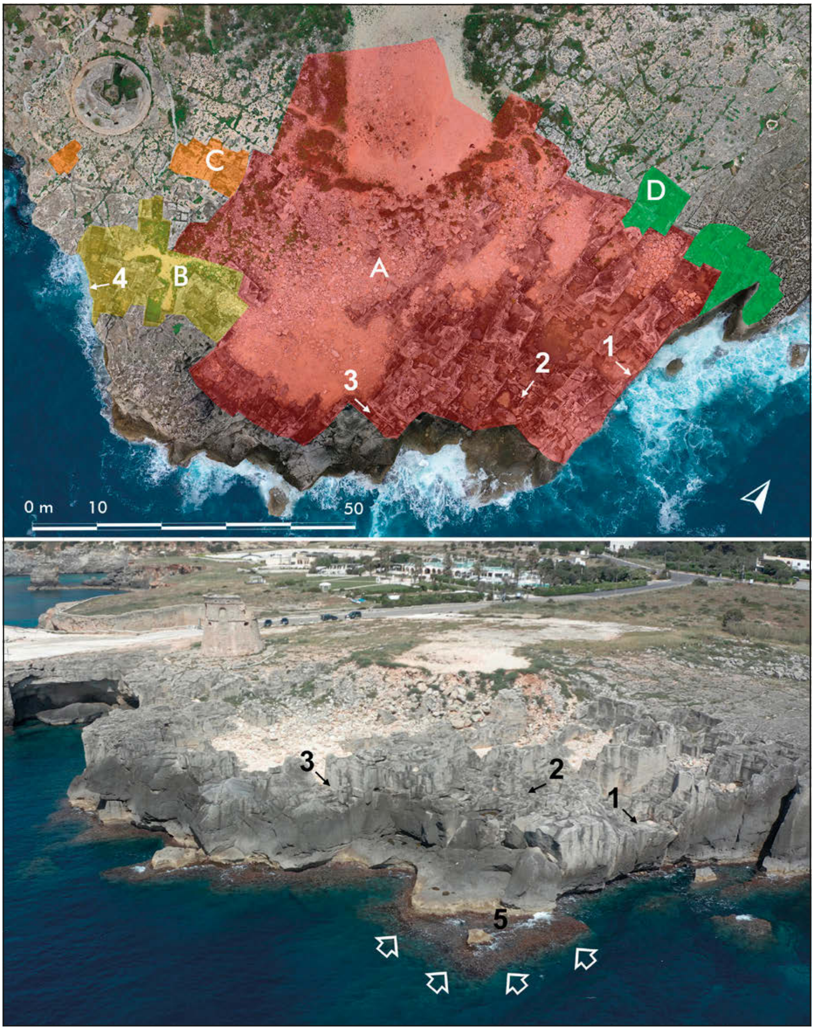

Fig. 4 – Porto Miggiano, cava principale: in alto, ortofoto da drone in cui sono evidenziati i vari settori estrattivi (A-D), corrispondenti a diverse fasi di coltivazione, e sono indicati gli accessi a mare (1-4); in basso, veduta aerea obliqua da S in cui compare la piattaforma (5), oggi semi-sommersa, che probabilmente veniva utilizzata per il carico dei blocchi su imbarcazioni.

accedere direttamente alla linea di costa (Fig. 4, nn. 1-3). Due di essi, in particolare, conducono a una piattaforma, oggi sommersa sotto 50-80 cm d'acqua, che sembra essere stata appositamente spianata e dai margini molto regolari (Fig. 4, n. 5), raggiungibile mediante uno scivolo: fornita di possibili bitte di ormeggio, essa doveva costituire una banchina funzionale al carico dei blocchi su imbarcazioni, anche valutando che in epoca ellenistica il livello del mare poteva essere in questa zona anche 2-2,5 m più basso, garantendone quindi una maggiore facilità di utilizzo. A tal proposito, va infatti evidenziato che, sebbene la mappatura e l'analisi dei marker geo-archeologici di variazione del livello marino costituiscano una documentazione da utilizzare sempre con molta cautela, per il tratto di costa adriatica subito a N di Brindisi (siti di Torre Santa Sabina e Torre Guaceto/Scogli di Apani) è attestato che in epoca tardo-repubblicana il mare dovette stazionare fino a -2,5 m rispetto alla sua posizione attuale (Auriemma *et al.* 2005; Scarano *et al.* 2008), mentre ancora più a N, a Egnatia, è stato calcolato che nel I sec. a.C. il livello sarebbe stato di ca. 3 m al di sotto di quello odierno (Auriemma, Mastronuzzi, Sansò 2004; Mastronuzzi *et al.* 2017; sulla problematica delle variazioni del livello del mare lungo le coste pugliesi durante l'Olocene, cfr. anche Auriemma, Mastronuzzi, Sansò 2003).

All'alloggiamento delle macchine lignee destinate al sollevamento dei blocchi sono poi probabilmente funzionali i vari incassi circolari e quadrangolari visibili nell'area immediatamente soprastante la piattaforma (per le operazioni di trasporto dei blocchi fino al punto di imbarco, di carico mediante argani di legno e di trasporto via mare a partire dalle cave costiere, Felici 2020). Il trasporto avveniva forse su imbarcazioni simili a zatteroni, con o senza prua e poppa (o con queste due parti sostanzialmente identiche per agevolare le operazioni di ingresso e uscita dalle aree di carico e scarico: cfr. *infra* Fig. 10), i quali potevano facilmente raggiungere il porto di Castro con una tranquilla navigazione sotto costa di appena 2,5 miglia marittime (sulle *naves lapidariae*, cfr. Gianfrotta 2008, 86-87).

La maggiore antichità di questo settore della cava rispetto agli altri è anche evidenziata dal fatto che le tracce di piccone e di cunei sui suoi fronti di estrazione sono meno visibili a causa dell'erosione subìta dalla roccia nel corso di molti secoli di esposizione agli agenti atmosferici; più "fresche" appaiono invece le tracce di stacchi, evidentemente più recenti, visibili negli altri settori estrattivi che sono stati identificati, oltre che sul letto di cava del settore più antico, da dove, in una seconda fase di coltivazione, che per la freschezza degli stacchi sembrerebbe di molti secoli successiva alla prima, sono stati cavati oltre un centinaio di dischi (diam. ca. 50-60 cm, alt. 20-30 cm; Fig. 6A-B) destinati alla realizzazione di *metae* e *catilli* di macine a mano per cereali. A tal proposito, va evidenziato che nel bacino del Mediterraneo esistono vari esempi di cave costiere caratterizzate dalla presenza di tracce lasciate dall'estrazione di questo tipo di manufatti, per lo più datate tra basso Medioevo e XVIII sec., comprendenti anche mole di macine di dimensioni più grandi, destinate alla frantumazione delle olive o dei grappoli d'uva (Lo Presti *et al.* 2014; Antonioli *et al.* 2017).

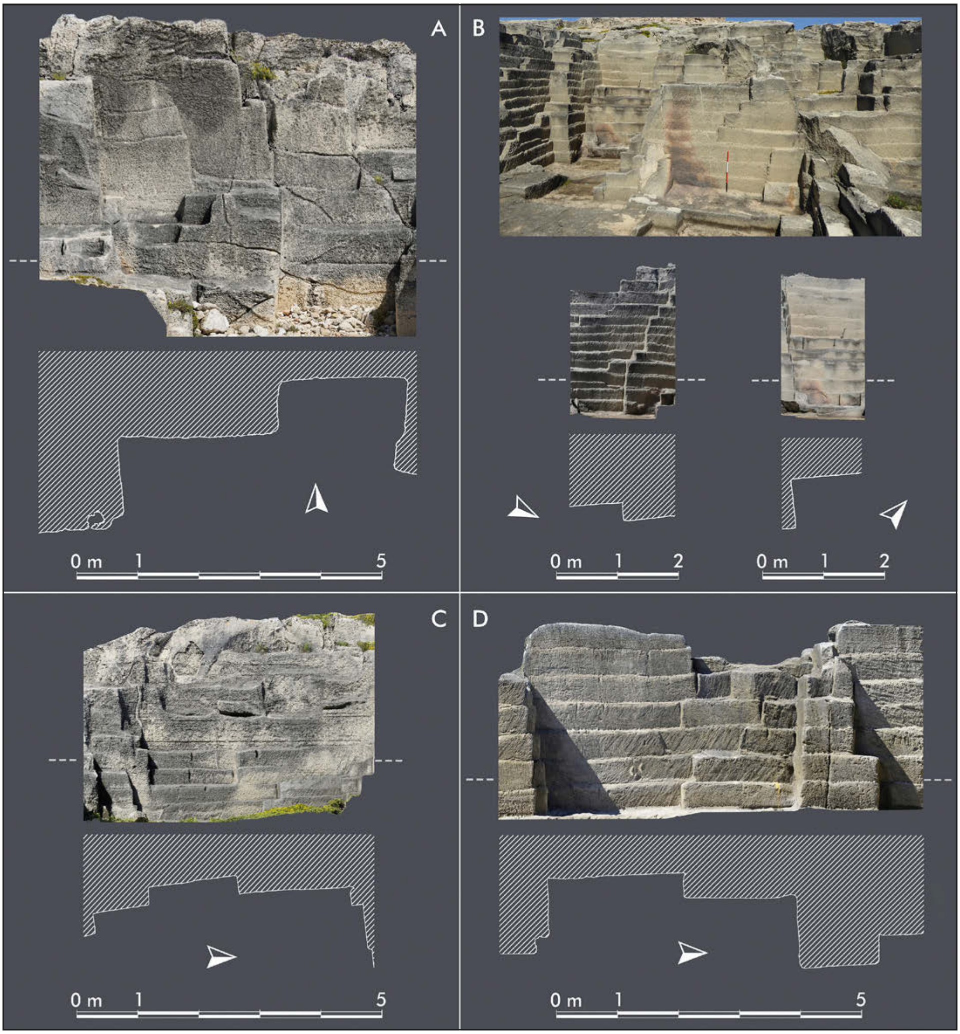

Fig. 5 – Porto Miggiano, cava principale: rilievi fotogrammetrici di alcuni fronti estrattivi.

Nel caso di Porto Miggiano, il numero dei dischi distaccati è davvero notevole e questa attività estrattiva (oltre a riguardare anche la superficie rocciosa subito a S e SO della torre) interessa sistematicamente tutta la porzione visibile del letto originario della cava, che oggi si presenta però in gran parte (settore centrale e settentrionale) coperto da detriti; questi sono stati scaricati da N per colmare la cava e realizzare un parcheggio turistico,

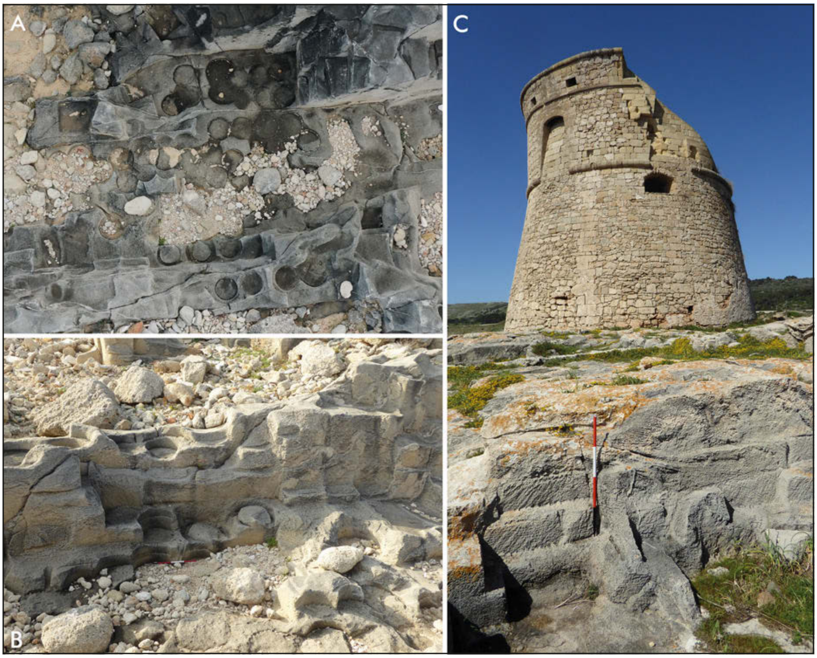

Fig. 6 – Porto Miggiano, cava principale: segni prodotti dal distacco di dischi per macine sul letto di cava del settore estrattivo più antico, documentati da drone (A) e da terra (B); settore estrattivo funzionale alla costruzione della torre (C).

e quindi il numero di dischi che è stato staccato potrebbe essere ancora più elevato. Ne consegue anche che il margine settentrionale della cava non risulta attualmente visibile, ma esso può essere integrato grazie a una foto aerea IGM del 1943 (Fig. 2B), che mostra l'area prima delle trasformazioni moderne a scopi turistici.

Gli altri tre settori della cava, piuttosto limitati, costituiscono ampliamenti posti in aree marginali rispetto al nucleo originario, che in alcuni casi tagliano. Uno (Fig. 4B), posto poco a S della torre e caratterizzato da fronti alti fino a 2,5 m, è stato sfruttato per estrarre blocchi alti 36-38 cm, lunghi fino a 78 cm e spessi 36 cm (Fig. 5B); nella sua porzione più occidentale si nota anche un intervento successivo, con le tracce di lavorazione che documentano l'estrazione di blocchetti alti 24-28 cm, lunghi fino a 64 cm e spessi 28 cm. La coltivazione di questo settore, molto vicino alla costa e che con uno dei *loci* estrattivi si apre sulla falesia (Fig. 4, n. 4), sembra essere stata funzionale all'approvvigionamento di un cantiere più distante, raggiungibile via mare; mancano elementi che possano suggerire una cronologia di questo settore estrattivo, ma l'elevata quantità del materiale estratto e le dimensioni

Fig. 7 – Porto Miggiano, cava a SO della torre: A) ortofoto da drone, in cui sono indicati i margini della piattaforma, oggi sommersa, utilizzata per caricare i blocchi; B-C) vedute da terra dei fronti e del letto di cava, in cui si riconoscono i segni dell'attività estrattiva e alcuni blocchi semi-distaccati e abbandonati.

dei blocchi staccati dalla roccia sembrano escludere un loro impiego nella vicina torre.

Alla costruzione della torre cinquecentesca, invece, sono stati verosimilmente destinati i blocchetti estratti da alcuni settori vicini all'edificio (Fig. 6C), poco profondi (1,20 m); i conci che vi sono stati staccati presentano infatti caratteristiche metrologiche comparabili a quelle del materiale messo in opera e tale impiego è stato confermato anche dalle analisi archeometriche (Alvarez de Buergo *et al.* 2008, 5-7; Quarta, Calia, Giannotta 2008, 668). La torre, a pianta circolare (diam. 12,50 m), è costruita in gran parte con pietrame irregolare (probabilmente quello risultante dalla rimozione della porzione più superficiale dei settori estrattivi), fatta eccezione per delle fasce verticali, realizzate a distanze regolari, e alcune porzioni del coronamento, che invece sono in blocchetti (alt. ca. 20 cm, lungh. 30-45 cm).

Probabilmente all'ultima fase di coltivazione della cava, da collocare alla fine dell'800 o ai primi del '900, sono infine riferibili due *loci* estrattivi posti all'estremità nord-orientale del sito (Fig. 4D), a una certa distanza dal mare, caratterizzati da fronti alti fino a 3,5 m (Fig. 5C) e dallo stacco di blocchetti di cm 19-26 (alt.), 39-40 (lungh.) e 17-18 (spess.); in questa fase, alcuni blocchetti delle stesse dimensioni sono stati asportati anche in alcuni punti dei vicini settori del nucleo originario della cava e, superficialmente, anche più a E. Si tratta di interventi paragonabili a quelli visibili anche nel territorio più all'interno e verosimilmente destinati alla costruzione dei primi edifici di Santa Cesarea Terme.

La seconda cava antica dell'area di Porto Miggiano occupa invece una superficie molto meno estesa (ca. 40×30 m) e si trova circa 150 m a SO della torre (Fig. 2B, n. 2), al livello del mare. Si tratta nuovamente di una cava a fossa, con fronti alti fino a 3,20-3,30 m e con tracce dell'attività estrattiva molto evidenti, dove si conservano blocchi semi-staccati e abbandonati (Fig. 7); i conci estratti (alt. 40 cm, lungh. 50-60 cm, spess. tra 35 e 55 cm; Fig. 5D) sono stati trasportati altrove tramite imbarcazioni, che, anche in questo caso, potevano verosimilmente attraccare subito a ridosso della cava, su una piattaforma con bordi regolarizzati, oggi parzialmente sommersa.

G.S.

3. Il rilievo laser scanner e la fotogrammetria da drone

Fondamentale per l'accurata documentazione dell'antica area estrattiva di Porto Miggiano è stata la realizzazione di una campagna di rilievo metrico utilizzando differenti tecniche di acquisizione, secondo modalità già sperimentate in precedenti progetti di ricerca (Ferrari, Giuri 2015; Leucci *et al.* 2019; De Giorgi *et al.* 2021). Data la complessa morfologia dell'area, per la restituzione metrica sono state utilizzate tecniche di rilievo strumentale basate sull'uso di sensori attivi e passivi, ovvero mediante l'utilizzo di laser scanner e tecniche di fotogrammetria digitale aerea. Quest'ultima ha consentito di integrare l'acquisizione laser scanner nelle porzioni fronte mare, irraggiungibili da terra, e di ottenere una mappatura colore in alta definizione utile alla lettura delle caratterizzazioni delle superfici (Leucci *et al.* 2019).

N° SCAN	POINTS	SCAN TIME AND RESOLUTION AT 10 M
1	50.764.115	spacing 3.1, quality level 3, time 13:30 min
2	49.607.669	spacing 3.1, quality level 3, time 13:30 min
3	49.159.246	spacing 3.1, quality level 3, time 13:30 min
4	47.510.710	spacing 3.1, quality level 3, time 13:30 min
5	50.016.892	spacing 3.1, quality level 3, time 13:30 min
6	197.194.182	spacing 3.1, quality level 4, time 26:59 min
7	40.760.680	spacing 3.1, quality level 3, time 13:30 min
8	36.685.128	spacing 3.1, quality level 3, time 13:30 min
9	57.002.621	spacing 3.1, quality level 3, time 13:30 min
10	51.412.698	spacing 3.1, quality level 3, time 13:30 min
11	45.059.664	spacing 3.1, quality level 3, time 13:30 min
12	45.301.684	spacing 3.1, quality level 3, time 13:30 min
13	56.879.519	spacing 3.1, quality level 3, time 13:30 min
14	59.447.624	spacing 3.1, quality level 3, time 13:30 min
15	59.398.917	spacing 3.1, quality level 3, time 13:30 min
16	59.297.933	spacing 3.1, quality level 3, time 13:30 min
17	47.999.661	spacing 3.1, quality level 3, time 13:30 min
18	48.274.993	spacing 3.1, quality level 3, time 13:30 min
19	48.276.774	spacing 3.1, quality level 3, time 13:30 min
20	48.522.070	spacing 3.1, quality level 3, time 13:30 min
21	48.421.141	spacing 3.1, quality level 3, time 13:30 min
22	40.332.925	spacing 3.1, quality level 3, time 13:30 min
23	38.942.755	spacing 3.1, quality level 3, time 13:30 min
24	42.265.116	spacing 3.1, quality level 3, time 13:30 min
Tot.	1.318.505.251	

Tab. 1 – Porto Miggiano, cava principale, rilievo laser scanner: parametri di acquisizione per singole stazioni.

L'impiego del laser scanner consente di riprodurre in ambiente 3D qualsiasi tipologia di superficie, con un'elevata accuratezza geometrica a partire da una maglia di restituzione sub-centimetrica, opportunamente definita in funzione delle superfici di riferimento. Nello specifico è stato impiegato il laser scanner topografico a tempo di volo Leica P20, in grado di acquisire sino a una distanza massima di 120 m con una velocità pari a 1 milione di punti al secondo (cfr. *supra* Fig. 3). Per la copertura totale dell'area, è stato necessario effettuare complessivamente 24 punti di stazione (Tab. 1), di cui 23 con un preset impostato su una dome di 10 m di raggio, avente spacing 3,1 mm, quality 3 e time 13:30, e il restante (posizionato in un'area centrale particolarmente aperta della cava e proprio per questo necessitante di una maggiore risoluzione) con spacing 3,1 mm, quality 4 e time 26:59 per coprire la parte più estesa del sito (Fig. 8A).

Successivamente si è proceduto al matching manuale secondo la procedura cloud to cloud utilizzando il software Leica Cyclone (v. 8.1.1), con

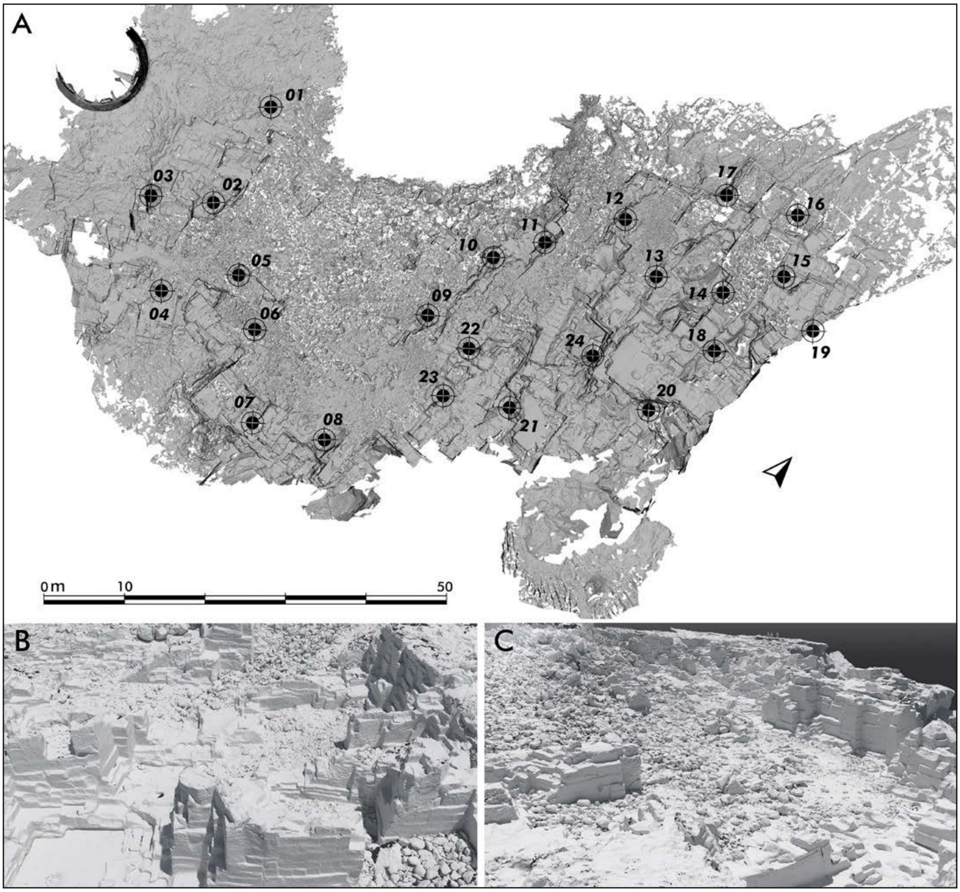

Fig. 8 – Porto Miggiano, rilievo laser scanner della cava principale: A) modello poligonale con punti di stazione; B-C) particolari da SO e da E.

un errore medio di allineamento di 0,016 m; la nuvola di punti finale è stata esportata in formato .pts (44,4 Gb; 1,3 mld di punti) e importata, decimata e processata in Geomagic (Studio 2003) per il calcolo della mesh poligonale in formato .obj (3,69 Gb; 34 mln di poligoni) (Fig. 8B-C).

La contestuale campagna di rilievo fotogrammetrico ha riguardato sia la documentazione a grande scala, che il dettaglio di specifici fronti di cava di particolare interesse. Riguardo la prima è stato necessario ricorrere ad acquisizioni aeree eseguite mediante UAV DJI Mavic 2 Pro, dotato di camera RGB ad alta risoluzione (20MPx). L'area complessivamente coperta si estende per circa 10.000 m² e presenta una morfologia complessa con variazioni di

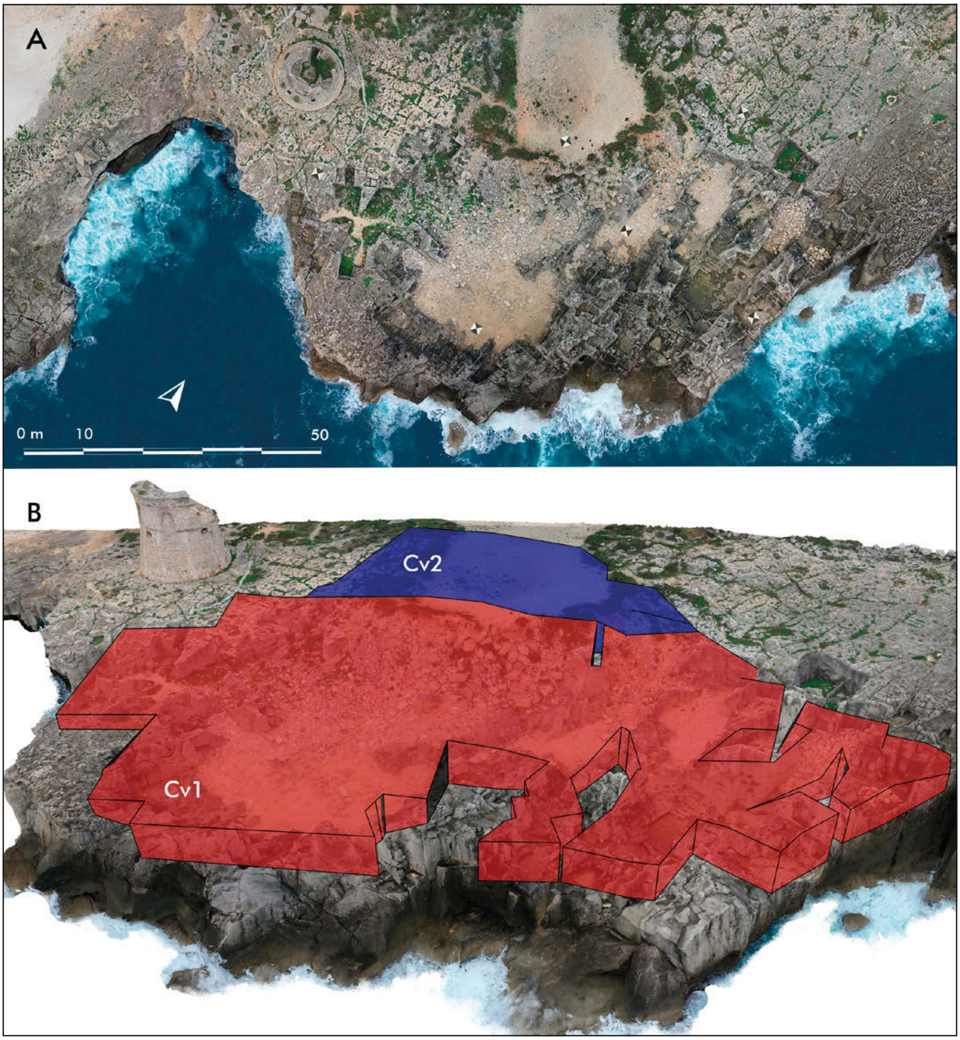

Fig. 9 – Porto Miggiano, cava principale: A) ortofoto da drone; B) calcolo del volume di materiale estratto nella porzione in luce (Cv1) e in quella interrata con materiale di riporto (Cv2).

quota che raggiungono i 5 m. Le operazioni di volo sono state precedute dal posizionamento di sei Ground Control Points (GCP) identificati da specifici target (80×80 cm) e rilevati utilizzando un ricevitore multifrequenze GNSS Emlid Reach RS2, con correzioni differenziali RTK direttamente dalla rete Hexagon SmartNet.

Per poter pianificare le missioni di volo automatico è stato utilizzato il software PIX4Dcapture, impostando parametri di quota, velocità, tempo di scatto della camera e percentuale di overlapping laterale/frontale. L'area in esame è stata acquisita compiendo tre sorvoli a un'altezza di circa 35 m s.l.m., il primo con camera nadirale e i restanti incrociati con camera posizionata a 30° per un totale di 152 foto RGB. Le immagini sono state quindi processate all'interno del software di fotogrammetria tridimensionale Agisoft Metashape Pro con i seguenti step: allineamento delle foto e creazione della nuvola di punti sparsa; inserimento delle coordinate GNSS sui relativi marker al suolo; correzione dell'allineamento delle foto sulla base delle coordinate note GNSS; creazione della nuvola ad alta densità (circa 67 milioni di punti); creazione del modello tridimensionale con texture; creazione del DEM e dell'ortofoto nadirale (8 mm/pixel) (Fig. 9A).

Per quanto concerne invece la documentazione dei fronti di cava, i dataset fotografici sono stati acquisiti tramite una camera digitale Sony Alpha 7R con obiettivo CANON EF 24MM F/1.4 L USM II, in parte con prese manuali e in parte con l'ausilio di un'asta telescopica provvista di un'estensione massima di 5 m. Gli scatti sono stati realizzati spostandosi parallelamente alle superfici a una distanza di circa 3 m, garantendo un overlapping minimo del 70%. Anche in questo caso l'elaborazione dei modelli 3D e dei fotopiani in scala è stata realizzata con Agisoft Metashape Pro (cfr. *supra* Fig. 5).

I.F., F.G.

4. Calcolo dei volumi estratti e proposta ricostruttiva dell'area di imbarco

Il rilievo digitale tridimensionale della cava principale, oltre alla documentazione dello *status quo*, è stato fondamentale sia nella stima dell'attività estrattiva in termini volumetrici (per la metodologia, cfr. Quarta *et al.* 2015), che nell'elaborazione di una proposta ricostruttiva di una porzione particolarmente significativa del sito, preposta all'imbarco dei blocchi mediante argani lignei.

Nel primo caso sono state individuate due macro-aree di estrazione: la porzione di cava in luce (Cv1: Fig. 9B, in rosso) e quella attualmente occultata da materiale di riporto (Cv2: Fig. 9B, in blu). Pertanto, ipotizzando come limite superiore la quota indicata dall'andamento naturale della costa e come limite inferiore il piano di cava, sono state simulate in 3D tutte le aree oggetto di estrazione e identificabili dalle tracce di lavorazione. A partire da questi modelli è stato possibile stimare un volume complessivo del materiale asportato di circa 11.354 m^3, suddiviso nelle singole aree secondo i valori espressi nella Tab. 2.

Fig. 10 – Porto Miggiano, cava principale, proposta ricostruttiva 3D dell'antico cantiere estrattivo e delle operazioni di trasporto e carico dei blocchi presso la piattaforma a S di esso (cfr. Fig. 4, n. 5): A) veduta panoramica da E; B) dettaglio della banchina di ormeggio.

La medesima riproduzione digitale è stata utilizzata come punto di partenza per l'elaborazione di una proposta ricostruttiva di una parte del cantiere estrattivo, dove si riscontra l'esistenza di uno sbocco diretto sul mare per la presenza di una banchina di ormeggio e carico del materiale

AREA	SUPERFICIE	ALT. MEDIA	VOLUME ASPORTATO
Cv1	2.520 m^2	3,65 m	9.198 m^3
Cv2	625 m^2	3,45 m	2.156 m^3

Tab. 2 – Porto Miggiano, cava principale: stima del volume di materiale estratto nella porzione in luce (Cv1) e in quella interrata con materiale di riporto (Cv2).

su imbarcazioni, verso la quale convergono due probabili rampe adoperate nella discesa dei blocchi estratti nei soprastanti fronti di cava. Si è proceduto, quindi, a realizzare alcune integrazioni direttamente sul modello digitale della cava per una ricostruzione dell'originaria morfologia della superficie rocciosa dell'area di cantiere che, per quanto indicativa, rimane tuttavia ancorata alle evidenze archeologiche documentate, grazie alle quali è stato possibile posizionare il livello del mare a una quota decisamente più bassa rispetto a quella attuale.

Nell'allestimento della scena in ambiente 3D (Maxon Cinema 4D R21 + V-Ray 5) sono state utilizzate tecniche hand-made modeling per la realizzazione dei modelli inerenti alle macchine da cantiere e alle imbarcazioni (per la metodologia, cfr. Gabellone 2006; Caruso *et al.* 2015; Gabellone, Ferrari 2017), facendo ricorso a un software specifico per la modellazione e messa in posa dei personaggi (Bondware Poser Pro 12.0.757 e relativo plugin per C4D InterPoser Pro v1.9). I render finali, basati su proposte ricostruttive presenti nella recente bibliografia archeologica relativa al trasporto di blocchi da cave costiere (Kozelj, Kozelj Wurch 1993; Felici 2020, figg. 8 e 12), mirano a proporre una rappresentazione 3D d'insieme (Fig. 10) che consenta di fornire una migliore e più immediata cognizione sia dello sviluppo topografico dell'area oggetto di studio, sia della sua plausibile articolazione, in un "modello di conoscenza" che si può configurare come sintesi dell'interpretazione dei dati raccolti (in proposito, cfr. Gabellone *et al.* 2017).

I.F., F.G.

5. Conclusioni

In base ai rilievi effettuati è stato possibile giungere a una restituzione schematica dei volumi di pietra asportati dalla cava principale di Porto Miggiano, pari a ca. 12.000 m^3, almeno l'80% dei quali da riferire alla più antica fase di coltivazione. A tal proposito, va evidenziato che questa cifra, tolto un verosimile scarto del 10%, compatibile con quello che si produce in una cava di pietra tenera, è molto coerente con il materiale che si può stimare sia stato messo in opera nella terza fase delle mura di Castro, per la quale si può calcolare che siano stati impiegati ca. 8500 m^3 di calcarenite.

In conclusione, se da un lato le ricerche condotte tra Santa Cesarea Terme e Marina Serra hanno evidenziato come tutto il settore della costa adriatica vicino a Castro, oltre che il territorio più all'interno, sia stato oggetto di un sistematico utilizzo degli affioramenti di pietra adatta alle costruzioni (Scardozzi 2023), dall'altro le cave di Porto Miggiano rivestono sicuramente un'importanza fondamentale, poiché molto più degli altri siti estrattivi conservano in gran parte ancora in maniera evidente l'aspetto originario, non alterato da successive coltivazioni. Insieme ai resti archeologici messi in luce a Castro, queste cave rappresentano quindi un'eccezionale testimonianza, assolutamente da conservare e tutelare, dell'esteso sfruttamento delle risorse naturali funzionali ai cantieri del Santuario di Atena e del successivo *castrum* tra IV e II sec. a.C.

G.S.

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BIBLIOGRAFIA

Alvarez de Buergo M., Masini N., Perez-Monserrat E., Calia A., Varas M.J., Quarta G., Fort R., Giannotta M.T., Vazquez-Calvo C., Danese M., Sileo M. 2008, *Geomonumental routes: The granitic bridges over the Guadarrama River (Madrid, Spain) and the calcarenitic coastal towers from the Salento (Italy)*, in J.W. Łukaszewicz, P. Niemcewicz (eds.), *Proceedings of the 11th International Congress on Deterioration and Conservation of Stone (Torun 2008)*, Torun, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, 1153-1161.

Antonioli F., Mourtzas N., Anzidei M., Auriemma R., Galili E., Kolaiti E., Lo Presti V., Mastronuzzi G., Scicchitano G., Spampinato C., Vacchi M., Vecchio A. 2017, *Millstone quarries along the Mediterranean coast: Chronology, morphological variability and relationships with past sea levels*, «Quaternary International», 439, Part A, 102-116.

Auriemma R. 2004, *Salentum a salo. Porti, approdi merci e scambi lungo la costa adriatica del Salento*, I-II, Galatina, Congedo Editore.

Auriemma R., Mastronuzzi G., Sansò P. 2003, *I siti archeologici costieri pugliesi come markers delle variazioni del livello del mare*, in *Ambiente e paesaggio nella Magna Grecia. Atti del XXXXII Convegno di Studi sulla Magna Grecia (Taranto 2002)*, Taranto, ISAMG, 515-521.

Auriemma R., Mastronuzzi G., Sansò P. 2004, *Middle to Late Holocene relative sea-level changes recorded on the coast of Apulia (Italy)*, «Géomorphologie: relief, processus, environnement», 10, 1, 19-33.

Auriemma R., Mastronuzzi G., Sansò S., Zongolo F. 2005, *The harbour of the Mansio ad Speluncas (Brindisi, Italy): A key to the history of sea level changes in the past 3500 years?*, in I. Marcel *et al.* (eds.), *Maritime Heritage and Modern Ports*, Southampton, Wessex Institute of Technology Press, 5-14.

Belotti B. 1997, *Un exemple de prospection systématique au sol: histoire de la ville de Vaste et de son territoire (prov. de Lecce)*, in F. D'Andria (ed.), *Metodologie di catalogazione dei Beni Archeologici, I. Beni Archeologici. Conoscenza e Tecnologia, Quaderno 1.1*, Lecce-Bari, Martano Editore-Edipuglia, 135-166.

Bossio A., Mazzei R., Monteforti B., Salvatorini G. 2005, *Stratigrafia del Neogene e Quaternario del Salento sud-orientale (con rilevamento geologico alla scala 1:25.000)*, «Geologica Romana», 38, 31-60.

Buscemi Felici G., Felici E., Lanteri L. 2020 (eds.), *Produzioni antiche sulla costa sud orientale della Sicilia. Saggi di topografia antica litoranea*, Bari, Edipuglia.

Calia A., Giannotta M.T., Quarta G., Sileo M., Delle Rose M. 2011, *Le antiche cave nei depositi calcarenitici lungo la costa pugliese: un esempio di geoarcheositi da tutelare e valorizzare*, in M. Bentivenga (ed.), *Il Patrimonio geologico: una risorsa da proteggere e valorizzare. Atti del Convegno Nazionale (Sasso di Castalda, Potenza, 2010)*, «Rivista della Società Italiana di Geologia Ambientale», Suppl. al n. 2, 265-273.

Caruso F., Gabellone F., Ferrari I., Giuri F. 2015, *New reconstructive proposal for a critical reading of the archaeological documentation of Syracuse in Greek times*, «Virtual Archaeology Review», 6, 12, 19-28.

D'Andria F. 2009, *L'Athenaion di Castro*, in F. D'Andria (ed.), *Castrum Minervae*, Galatina, Congedo Editore, 13-66.

D'Andria F. 2020, *L'Athenaion di Castro in Messapia*, «Römische Mitteilungen», 126, 79-140.

D'Andria F., Degl'Innocenti E., Caggia M.P., Ismaelli T., Mancini L. 2023, *Athenaion. Tarantini, Messapi e altri nel Santuario di Atena a Castro*, Bari, Edipuglia.

De Giorgi L., Ferrari I., Giuri F., Leucci L., Scardozzi G. 2021, *Integrated geoscientific surveys at the Church of Santa Maria della Lizza (Alezio, Italy)*, «Sensors», 21, 2205, 1-17.

De Mitri C. 2009, *Castro. Lo scavo di località "Muraglie": nuovi dati sul circuito murario di età messapica*, in F. D'Andria (ed.), *Castrum Minervae*, Galatina, Congedo Editore, 121-197.

Felici E. 2020, *Dalla latomia al cantiere. Il trasporto nautico della pietra*, in Buscemi Felici, Felici, Lanteri 2020, 147-174.

Ferrari I., Giuri F. 2015, *Rilievo e restituzione grafica delle aree delle Pozzelle di Pirro e di Apigliano*, in A. Chiga, P. Durante, S. Giammaruco (eds.), *Conservare l'acqua. Le pozzelle di Zollino tra memoria storica e indagini scientifiche*, Galatina, Editrice Salentina, 63-70.

Gabellone F. 2006, *Hand made 3D modelling for the reconstructive study of Temple C in Selinunte: Preliminary results*, in G. Gallo, S. Battiato, F. Stanco (eds.), *Proceedings of the 4th Eurographics Italian Chapter Conference (Catania 2006)*, Catania, Eurographics, 1-7.

Gabellone F., Ferrari I. 2017, *Reconstruction of Villino Florio's wooden ceiling using 3D technologies*, in Garagnani, Gaucci 2017, 587-590 (https://doi.org/10.19282/AC.28.2.2017.49).

Gabellone F., Ferrari I., Giuri F., Chiffi M. 2017, *3D technologies for a critical reading and philological presentation of ancient contexts*, in Garagnani, Gaucci 2017, 591-595 (https://doi.org/10.19282/AC.28.2.2017.50).

Galati A. 2015a, *Castro. 2, Castello, torre Est*, «Taras. Notiziario delle attività di tutela», n.s. 2, 258-259.

Galati A. 2015b, *Castro. 3, Piazza Perotti*, «Taras. Notiziario delle attività di tutela», n.s. 2, 259.

Garagnani S., Gaucci A. (eds.) 2017, *Knowledge, Analysis and Innovative Methods for the Study and the Dissemination of Ancient Urban Areas*, Proceedings of the KAINUA 2017 International Conference (Bologna 2017), «Archeologia e Calcolatori», 28, 2 (http://www.archcalc.cnr.it/journal/idyear.php?IDyear=2017-01-07).

Gianfrotta P.A. 2008, Σμειριδες*: depositi portuali, marmi di cava e navi*, «Orizzonti», 9, 77-89.

Guaitoli M. 1997, *Attività dell'Unità operativa Topografia antica*, in F. D'Andria (ed.), *Metodologie di catalogazione dei Beni Archeologici, I. Beni Archeologici. Conoscenza e Tecnologia, Quaderno 1.2*, Lecce-Bari, Martano Editore-Edipuglia, 9-45.

Ismaelli T. 2020, *I fregi a girali abitati dell'Athenaion di Castro. Iconografia e linguaggio formale di una creazione tarentina*, «Römische Mitteilungen», 126, 141-203.

Kozelj T., Kozelj Wurch M. 1993, *Le transports dans l'antiquité*, in R. Francovich (ed.), *Archeologia delle attività estrattive e metallurgiche*, Firenze, All'Insegna del Giglio, 97-142.

Largaiolli T., Martinis B., Mozzi G., Nardin M., Rossi D., Ungaro S. 1969, *Note illustrative della Carta Geologica d'Italia alla scala 1:100.000, Foglio 214, Gallipoli*, Ercolano, Poligrafica & Cartevalori.

Leucci G., De Giorgi L., Ditaranto I., Giuri F., Ferrari I., Scardozzi G. 2019, *New data on the Messapian necropolis of Monte D'Elia in Alezio (Apulia, Italy) from topographical and geophysical surveys*, «Sensors», 19, 3494, 1-26.

Lippolis E., Mazzario N. 1981, *Castro. Rinvenimento di mura preromane*, «Taras», 1, 1, 43-52.

Martinis B. 1970, *Note illustrative della Carta Geologica d'Italia alla scala 1:100.000, Foglio 223, Capo S. Maria di Leuca*, Ercolano, Poligrafica & Cartevalori.

Lo Presti V., Antonioli F., Auriemma R., Ronchitelli A., Scicchitano G., Spampinato C.R., Anzidei M., Agizza S., Benini A., Ferranti L., Gasparo Morticelli M., Giarrusso C., Mastronuzzi G., Monaco C., Porqueddu A. 2014, *Millstone coastal quarries of the Mediterranean: A new class of sea level indicator*, «Quaternary International», 332, 126-142.

Margiotta S., Sansò P. 2017, *Abandoned quarries and geotourism: An opportunity for the Salento quarry district (Apulia, Southern Italy)*, «Geoheritage», 9, 463-477.

Mastronuzzi G. 2015, *Castro. 1, Capanne*, «Taras. Notiziario delle attività di tutela», n.s. 2, 256-258.

Mastronuzzi G., Antonioli F., Anzidei M., Auriemma R., Alfonso C., Scarano T. 2017, *Evidence of relative sea level rise along the coasts of central Apulia (Italy) during the late Holocene via maritime archaeological indicators*, «Quaternary International», 439, 65-78.

Previato C. 2016, *Nora. Le cave di pietra della città antica*, Roma, Edizioni Quasar.

Quarta G., Calia A., Giannotta M.T. 2008, *Caratteristiche minero-petrografiche e geochimiche di calcareniti da cave costiere della penisola salentina: contributo allo studio dello sfruttamento nell'antichità*, in G. Oggiano *et al.* (eds.), *Atti dell'84° Congresso Nazionale della Società Geologica Italiana (Sassari 2008)*, Roma, Società Geologica Italiana, 667-668.

Quarta G., Giannotta M.T., Giuri F., Sansò P., Vitale A. 2015, *Identification of an ancient limestone quarry on the Ionian coast of Southern Apulia (Southern Italy): Rock characterization and new data about its exploitation over time*, in *Abstracts of Asmosia XI Conference (Split 2015)*.

Ricchetti G., Ciaranfi N. 2013, *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 537, Capo Santa Maria di Leuca*, Firenze, Litografia Artistica Cartografica.

Scarano T., Auriemma R., Mastronuzzi G., Sansò P. 2008, *L'archeologia del paesaggio costiero e la ricostruzione delle trasformazioni ambientali: gli insediamenti di Torre Santa Sabina e Torre Guaceto (Carovigno, BR)*, in *Il monitoraggio costiero mediterraneo: problematiche e tecniche di misura. Proceedings of the 2nd International Conference (Napoli 2008)*, Firenze, CNR-IBIMET, 391-402.

Scardozzi G. 2023, *Costruire il Santuario: lo sfruttamento delle cave di calcarenite*, in D'Andria *et al.* 2023, 173-181.

Tropeano M., Spalluto L., Moretti M., Pieri P., Sabato L. 2004, *Depositi carbonatici infrapleistocenici di tipo foramol in sistemi di scarpata (Salento - Italia meridionale)*, «Il Quaternario. Italian Journal of Quaternary Sciences», 17, 2/2, 537-546.

Zezza F., Bruno G. 1991, *Caratteristiche geo-meccaniche e problemi di instabilità della falesia di Porto Miggiano (Puglia)*, «Geologia Applicata e Idrogeologia», 26, 273-291.

ABSTRACT

The ISPC-CNR is conducting research activities aimed at identifying ancient quarries that supplied the public building sites in the Athenaion of Castro, where excavations revealed dry-stone city walls made of calcarenite blocks and built in three phases between the 4th and 2nd cent. BC. The paper is focused on the large coastal quarries of Porto Miggiano, located approximately 4.5 km NE of Castro, where the extraction was carried out in function of sea transportation of the blocks. The extraction sites were documented through laser scanning and photogrammetry by a drone. In the main quarry, which covers an area of approximately 0.4 hectares, thanks to the metrological analysis of the stepped faces, four extraction areas were identified corresponding to at least five cultivation phases. The oldest and most extensive one affects the central sector of the quarry, where large blocks compatible (for dimension and macroscopic aspect) with those of the third phase of the Castro city walls, dated to the beginning of the 2nd cent. BC, were extracted.

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DIGITAL TECHNOLOGIES AND THE ARCHAEOLOGICAL TOPOGRAPHY OF CASTELLITO (SICILY): THE RECONSTRUCTION OF A ROMAN VILLA

1. Introduction

This paper focuses on the use of digital technologies and the potential of 3D computer-based visualization as research tools to support the interpretation and modelling of archaeological data during the field work carried out in the site of Castellito di Ramacca (Catania, Sicily) (Fig. 1) (Spigo 1982-1983; Albanese Procelli, Procelli 1988-1989, 7-22; Patanè 1997-1998, 200-201, n. 146 and Patanè 2001). A tested workflow of 3D modelling and visualization applied to the case study of the Roman villa of Castellito will be described. It will further explore how the 3D model of the archaeological excavation, obtained with photogrammetric techniques, has been used in combination with the reconstructive 3D model (Bezzi *et al.* 2010; De Felice, Sibilano 2010; Ferdani *et al.* 2019).

Castellito is one of the few contexts attributable to an early imperial age Roman villa located on the western edge of the Plain of Catania (Brancato 2020a, 292-298). The site was partly excavated in the second half of the 20th century and interpreted as a *villa rustica*, likely related to the *massa Capitoniana* attested in ancient sources (for an up-to-date review of Roman villas in Sicily, Sfameni 2019, 233-236; see also Wilson 1990, 194-214). The building, located on the top of a low hill (106 m asl) W of the Dittaino river, extended over an area of at least two thousand square metres (Fig. 2a). Built during the early Imperial age, its role as a central place declined during the fourth century CE, not experiencing the outstanding architectural development that characterized other villa contexts in Sicily and in the Mediterranean region (Sfameni 2006, with references).

2. Applied methods

2.1 *Legacy data integration*

The resumption of investigations in the site was preceded by the systematic examination of the bibliography and archives, in order to verify what had already been documented in the past but remained substantially unpublished (Brancato 2019a). The new programme of research at Castellito began in 2019 with the digitization process of the available archaeographic data for the site (Brancato 2019b; see also Anichini, Gattiglia 2012). The GIS management of data from previous research, the so-called legacy

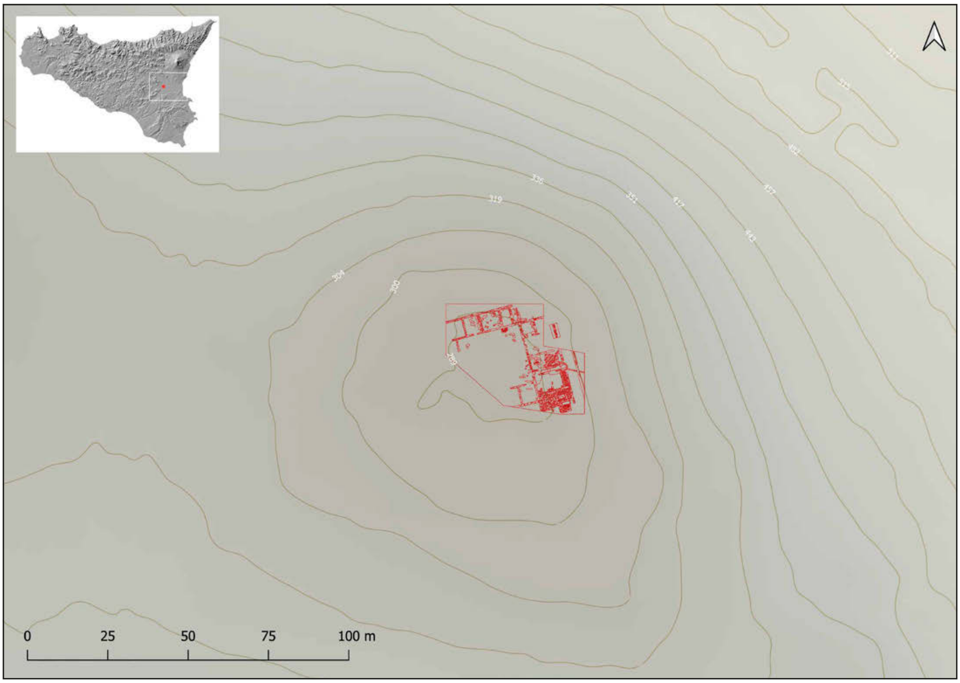

Fig. 1 – Location of the Castellito villa site in Ramacca (Catania, Sicily) (in red) on a topographic map obtained from a 2×2 m LiDAR Composite DTM (ATA 2007-2008, Regione Sicilia).

data (Bogdani 2020), enabled their integration with the new archaeological and topographical data collected in the field. The detailed analysis of the legacy data (including photographic documentation, graphics, inventories, excavation journals, written reports, etc.) made it possible to understand how much of the site had already been brought to light and then covered up in the past: it is clear that this undertaking was of fundamental importance to understand the extent of the taphonomic processes that have affected the archaeological deposit and to establish the necessary relationships between the few data already known and those derived from the new planned activities.

The discovery of the site, and its unfortunate history, has to be seen in the context of the indirect effects deriving from the reclamation of the Piana di Catania carried out in the first half of the 20th century (Brancato 2020b). The southern sector of the villa was probably destroyed during these years: in fact, from the analysis of an aerial photo from 1967 it is possible to infer that the archaeological site had already been seriously affected by the planting of olive trees (Brancato 2020b). Archaeological proper research on the site began in 1978 (Albanese Procelli, Procelli 1988-1989), when seven trenches

Fig. 2 – View on the archaeological site of Castellito (top): the remains of the NW sector of the villa with Mount Etna in the background. Planimetric palimpsest of topographic legacy data from previous research campaigns carried out in the site (bottom).

(A-G) were excavated in order to assess its extent. In 1995, the resumption of research revealed the structures, which were documented in a partial plan (Patanè 1997-1998)[1]. The synoptic analysis of the graphic documentation from the archival research made it possible to arrange a digital palimpsest of previous investigations. The planimetric documentation, properly digitized, was georeferenced in a GIS environment (Fig. 2b). The georeferencing process involves establishing a set of ground control points – known x, y coordinates – that link positions on the raster dataset with positions in the spatially referenced data.

Indeed, the process of georeferencing heterogeneous topographic data (e.g., a scanned map or aerial photograph) makes it possible for them to appear "in place" within the GIS. By associating features of the scanned image with real-world x and y coordinates, the software can progressively deform the image so that it fits other spatial datasets. Unfortunately, at the moment it is not possible to reconstruct the succession of actions that have affected the archaeological deposit of some sectors of the area. However, within the geo-referenced basis on which the new survey project of the site was set up, the available archaeographic documentation converged: the GIS management of the data from previous research allowed their profitable integration with the archaeological and topographical data that emerged during the new research conducted on the site from May 2019 (Fig. 3)[2].

R.B.

2.2 *UAV-based photogrammetry*

The drafting of the archaeological, digital and multiscalar documentation of the site was conducted through the integration of traditional survey techniques and remote/proximal sensing for aerial and terrestrial photogrammetry, exploiting the potential of each method in order to maximize the final result (Russo *et al.* 2011; Campana 2017). The first step was the planning of several aerial photogrammetric surveys by means of a UAV to understand the extent of the site and to analyze the relationships between the different sectors of the archaeological complex (Fig. 3). The photographic datasets were obtained by flying over the area at low altitude (about 30 m above ground level) while maintaining a high frontal and lateral overlap between shots (≥ 80%) and making use of known points on the ground, surveyed using a GNSS antenna

[1] Before 1995, the site had been largely excavated under the direction of E. Tomasello (Superintendence of Catania): unfortunately, there is no documentation of this activity, nor has it been possible to reconstruct the contexts of the discovery of the materials now in storage at the Ramacca Civic Museum.

[2] This paper presents the results of the fieldwork carried out within the agreement between the University and the Superintendence of Catania (2019-2021) under the direction of M.T. Magro to whom goes the deepest gratitude for her engagement in the salvage project of Castellito's mosaics.

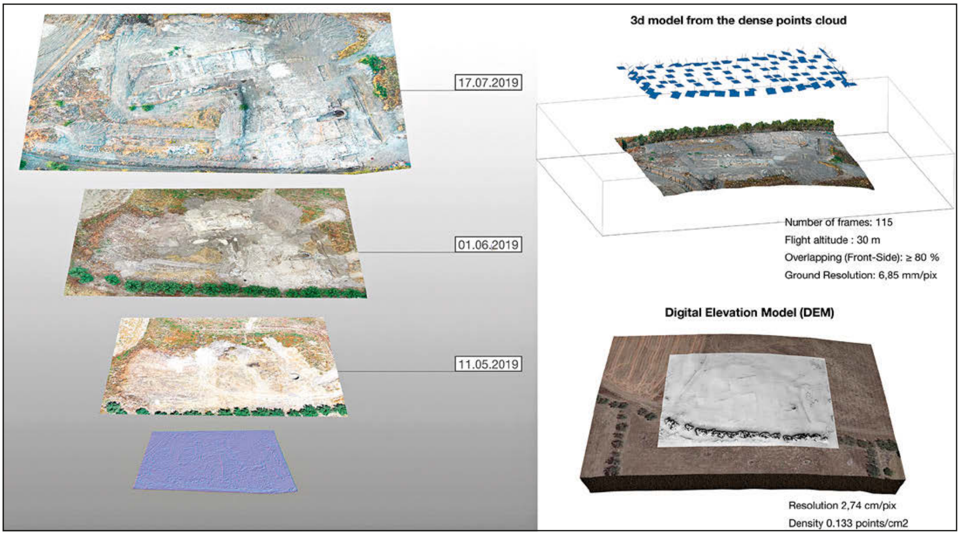

Fig. 3 – Sequence of flight missions and restitution of the Digital Elevation Model.

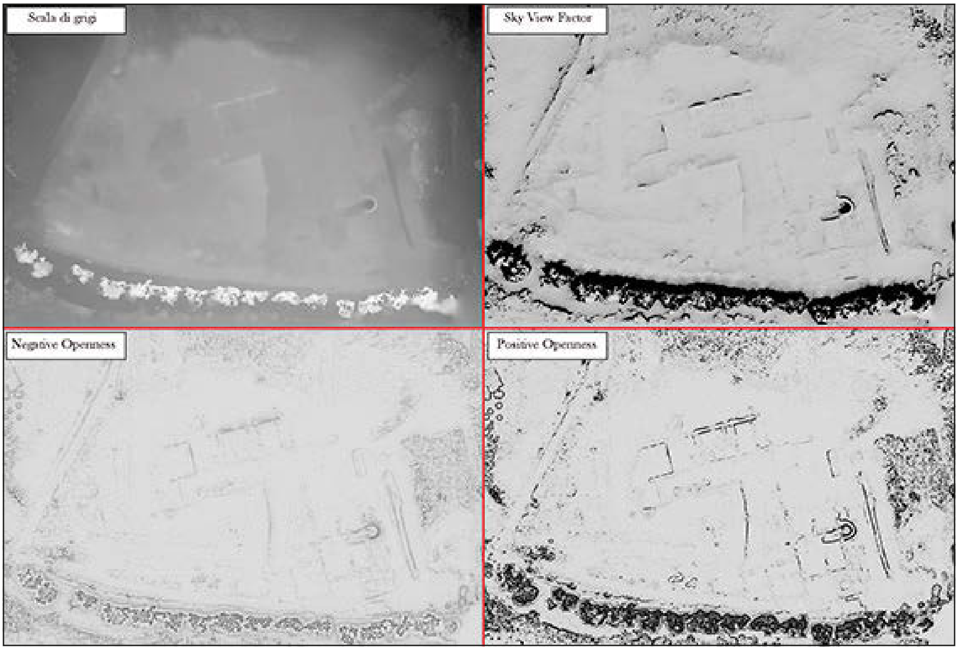

Fig. 4 – Comparison between different relief visualization techniques on the Digital Elevation Model.

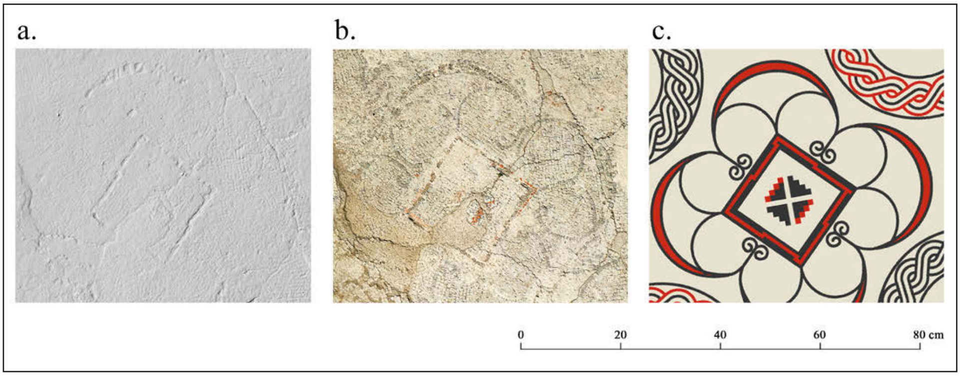

Fig. 5 – From the analysis of the micro-relief to the digital restoration of the mosaics.

in RTK (Real Time Kinematic) mode. Once the floors of the individual sectors of the villa were brought to light, they were documented using a camera with an FX sensor installed on a telescopic rod. This has made it possible to acquire the very high-resolution images necessary for the digital reconstruction of the decorative motifs of the mosaic floors, and to document the building techniques used during the various occupation phases of the complex. The data acquired in the field were subsequently processed using SfM (Structure from Motion) software, returning high-resolution 3D models, orthophotos and DEMs (Digital Elevation Models), which proved decisive both for the typological characterization of the site and for delineating the planimetric development of the structures[3].

The orthophotos of the floor plans, in particular, constitute the basic documentation on which the hypotheses of digital reconstruction of the decorative motifs and chromatic features were subsequently developed (Fig. 5). Moreover, through the processing of the DEMs in a GIS environment it was possible to carry out an analysis of the micro-relief, through specific visualization techniques such as Sky View Factor and Openness, which make it possible to significantly increase the degree of visibility of the positive and negative anomalies of a given element, adapting both to the morphology of the terrain (Fig. 4) and, in this case, also to the surface of the mosaic floors (Challis *et al.* 2011; Kokalj *et al.* 2011). During the work, thanks to the periodic cadence of the aero photogrammetric surveys, it was possible to identify several areas in which the previous archaeological documentation had gaps, and which were therefore made a focus of

[3] The site's 3D model (date of flight: 17.07.19 - Mesh face count: 500.000) obtained from aerial photogrammetry can be viewed on Sketchfab at the following link: https://skfb.ly/oEvn7.

activity. Thus, the use of photogrammetry allowed a thorough analysis of the entire context, generating a qualitative and quantitative increase in the archaeological data surveyed, with rapid acquisition times and particularly low costs when compared to those inherent in range-based instrumentation, such as laser scanners and LiDAR sensors, while still guaranteeing a high level of accuracy in the final data.

V.M.

2.3 *Architectural analysis*

The most notable achievement of the project is the first complete planimetric survey of the villa, conducted by a direct method with the help of photogrammetric material taken via drone and telescopic rod. Of the entire architectural complex, the quadrangular sector investigated measures 36×44 m. Oriented NE-SW, a total of 21 rooms gravitating around a peristyle measuring 19.8×19 m (52.25×54.45 Roman feet) were documented. The architectural design of the complex was originally strictly symmetrical, as is evident from the arrangement and concatenation of the numerous rooms arranged along the northern and southern sectors (Fig. 6).

During the archaeological work on the site, the application of an integrated approach calibrated to the scale of intervention made it possible to collect data not only on the topography and architecture of the villa, but also on its history. The stratigraphic analysis applied to the masonry and the few dating criteria arising from finds associated with the patches of surviving stratigraphy investigated allow us to suggest a preliminary sequence of the building's construction phases. Already in the course of the survey work, the existence of at least two construction phases had clearly emerged, in some cases with obvious overlapping of structures (SE corner), partial obliteration of the oldest floor levels (E wing) and the subdivision of rooms and changes in their use (N wing) (Fig. 7). The presence of white limestone blocks, some of considerable size, at the base of the walls and for in use as some of the thresholds could be a clue to the complex genesis of the early facility, a phase yet to be investigated. The few indications available might, however, suggest that these elements can be traced back to the phase of the building's foundation phase, the chronology of which is yet to be confirmed, but which on the basis of comparisons could be placed in the early imperial age. This at least is suggested by some materials and, above all, by a plan comparable to some coeval Sicilian rustic villas, among them the first phase of Patti Marina and phase V of S. Biagio, Terme Vigliatore (Tigano 2008).

In the villa's visible structures, the most widely seen building technique is that which has been identified with Phase II: a roughly-hewn and -squared irregularly-sized yellow sandstone ashlar facing, bonded with mortar of good

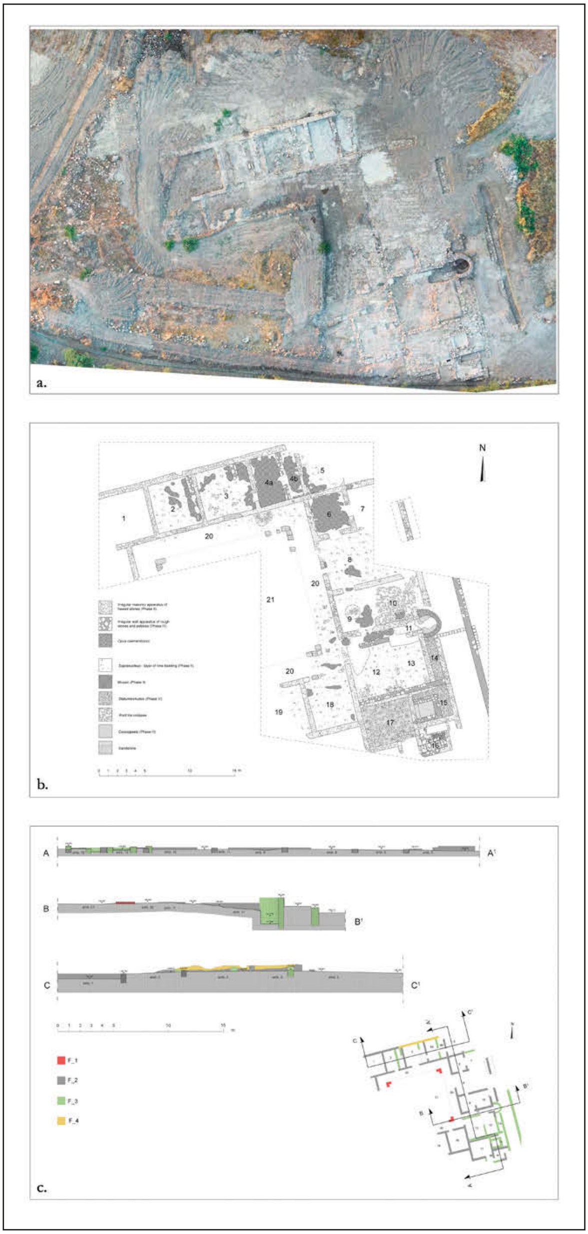

Fig. 6 – a) Orthophoto plan of the archaeological site at the culmination of mosaic restoration (July 2020); b) planimetry of the site with indication of building techniques; c) site plan and sections with an indication of the main construction phases.

Fig. 7 – View of structures belonging to the Phase II of the villa; the white arrow indicates the remaining red plaster fragment, zoomed in to the right.

quality and strength, to form walls 55 cm thick (Fig. 7). At this stage, the floor levels were uniformly provided with mosaic carpets with geometric decoration, and the walls certainly received a covering of red painted plaster, as a surviving fragment preserved in Room 4 seems to show (Fig. 7). A number of rebuilding efforts should probably be placed within this phase, including the construction of a cold apsidal basin perhaps closing the corridor of the eastern sector. Traces of fire under the collapse of Rooms 9 and 10 and signs of structural failure readable in some parts of the structure, on the basis of the material culture data, allow us to identify a caesura in the life of the villa in the second half of the fourth century, perhaps a consequence of the earthquake of AD 361, a traumatic event that left numerous traces in the monuments of eastern Sicily, notably in the villas of Piazza Armerina and Gerace (Wilson 2019).

The later structures (Phase III), about 60 cm thick, appear to be in *opus incertum* of medium- to large-sized river pebbles, bonded with low-quality earthy mortar (Fig. 7). The stability of the built structures, two cores that were perhaps not contiguous, was ensured by the construction of a retaining wall that was identified on the eastern side of the plateau. The two macro phases – also evidenced by the material culture, whose study is ongoing – clearly define sectors and rooms referable to different building situations in terms of both chronology and function. While the aristocratic nature of the villa is quite clear from the monumentality of the architecture, the degradation caused by agricultural work and clandestine excavations makes it very difficult to understand Phase III of the building. What remains allows us to propose a reoccupation of the site during the fifth century, probably with the insertion of a productive installation relating to the basin visible in the SE sector of the building (Fig. 8a, Room 15).

R.B.

2.4 *The mosaics*

The Castellito villa boasts a substantial number of mosaics, which are potentially diagnostic and of fundamental importance because of the wealth of information they can release. However, the severe degradation of the numerous surviving pieces and the widespread disruption of the mosaic fabric and the images represented have made the process of cognitive analysis and consequent digital restoration particularly complex (Moscati 2009; Limoncelli 2012). The work presupposed a lengthy preliminary phase of study and appreciation of the basic geometries and modules adopted, implemented by means of a direct and indirect tracing operation, replicating geometric portions in the CAD environment. The process of proportioning the individual compositions obtained was carried out by superimposing DWG files and orthophotos, taking account of variations in the images caused by surface sinkage or the detachment of *tesserae*. Working digitally allowed the creation of a complete working model of the whole space in 2D which could nevertheless later be altered as necessary.

The second part of the work involved the calculation of the thickness of each individual geometric element, derived from the measurements and quantity of the individual *tesserae*, and the chromatic reconstruction of the individual modules using Adobe Illustrator, trying to employ shades as close as possible to the original and enhancing the artistic dimension of the entire composition. Finally, the floors were placed in their specific original location, i.e. the floor plan of the original second-phase complex (Fig. 8a), reconstructed by referring to the contextually-made scale surveys and the technical-structural relationships of the many different wall structures.

The monoscopic terrestrial photogrammetry of the individual rooms and the digital restoration of the relevant floors were necessary for a functional reading of the rooms and for their dating on an iconographic and stylistic basis. They have also made it possible to record all the phases from the condition of the tessellations at the time of their discovery up to the restoration of their design and colour. The ten floors are uniformly characterized by linear and isotropic geometric mosaics, variously composed of white and black (b/w) or white, black and red (b/w/r) medium-sized *tesserae* (Grandi, Guidobaldi 2006, 36). The elements that make up the geometric patterns are annotated with the relevant measurements and bear the reconstruction of the modular geometric pattern generating the decoration (Fig. 8d). These elements comprise meandering swastikas in three distinct variants (Fig. 8b, Rooms 2, 6, 9), double-scored Solomon's knots associated with opposing *peltae* (Room 20) and pelta pinwheels (Room 8), circles and squares alternating with lozenges and triangles in the resulting spaces (Fig. 8c, Room 3), compositions of circles and quadrilobe *peltae*, free (Room 4) or inscribed in a circle (Room 5),

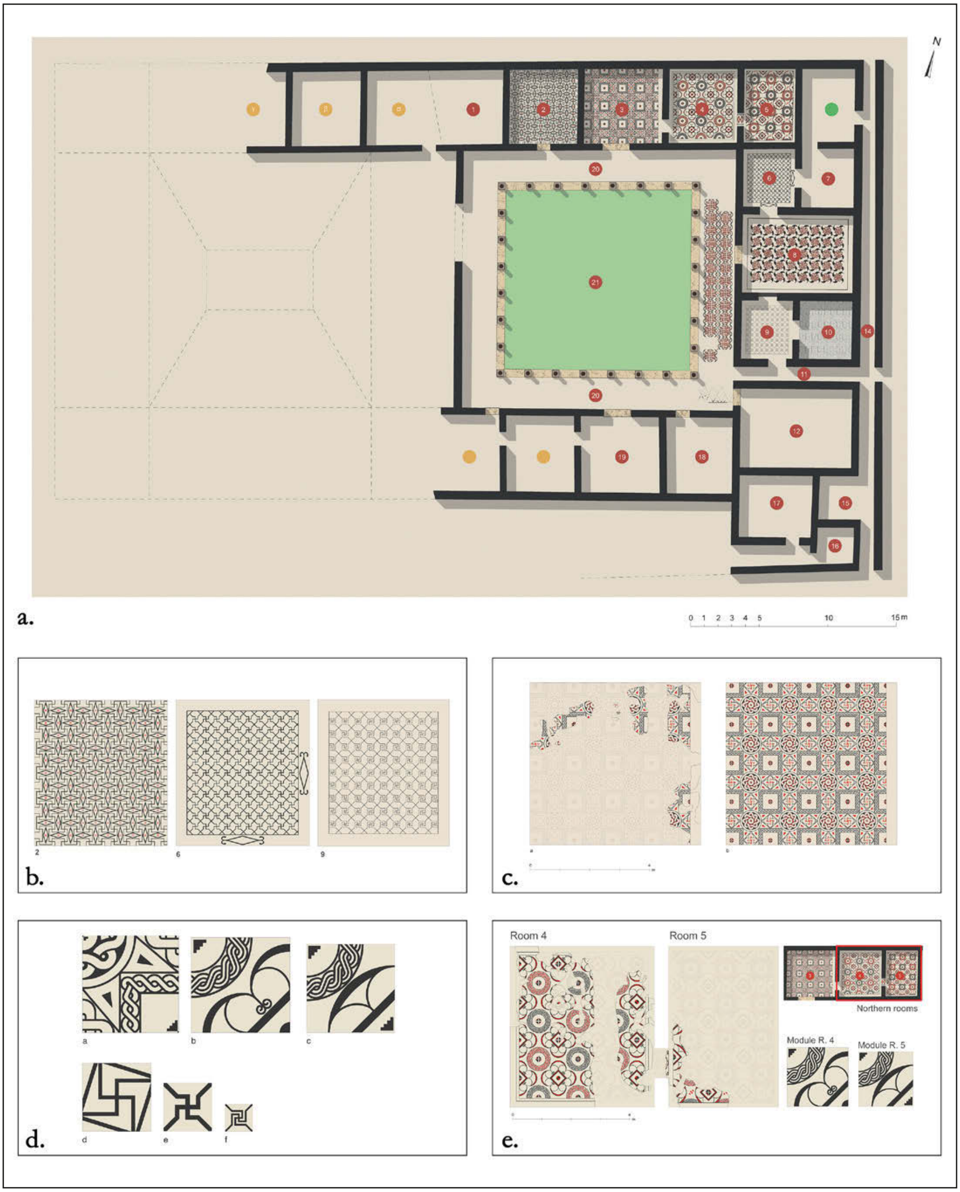

Fig. 8 – a) Graphic and chromatic restitution of the reconstructed plan of the villa in the mosaic phase; b) digital restoration of the floors of Rooms 2, 6, 9; c) reconstruction drawing of the floors of Room 3; d) basic geometries and forms adopted in the mosaics of the villa; e) reconstruction drawing of the floors of Rooms 4-5 and their respective modules.

isodomic-structured patterns (dallage) with white tiles arranged according to 'graphisms' (Room 10) and monochrome white carpets (Room 11).

The entire production is of a single period (Brancato *et al*. 2021, 251), but the distinct chromatic and iconographic features of the individual mosaics prompt a subdivision of the tessellations into two distinct groups and attest the survival of two different cultural phenomena in the same house. The first group, dominating in environments with a secondary function, has bichrome (b/w) patterns of ancient central Italic tradition (Brancato *et al*. 2021, 252-253), attested since the first century BC and widely reposted in the third (Rooms 2, 6, 9, 10, 11). The second is trichrome (b/w/r) and preferred in environments with a public or semi-public function (Rooms 3, 4, 5, 8, 20) and exhibits typologies that originated between the end of the second century AD and the latter part of the Severan age. An eloquent example is offered by the mosaic decoration recorded in the *cubicula* of the northern private apartment (Rooms 4 and 5): orthogonal compositions of circles and quadriconic figures generated by four strongly pronounced converging *peltae*, terminating in curled volutes and arranged outside the vertices of squares rotated on diagonals in Room 4 and differently inscribed in a circle in Room 5 (Fig. 8e).

This type of decoration, which probably originated in Italy in the black and white mosaics of the early imperial age (Cassieri 2000, 244-245, Fig. 8), seems start spreading at the end of the second century AD and then began to become more common during the third century, at first in the simplest form, later with growing complexity as more intricate decorative motifs were added within the geometric figures and in the resulting spaces, and then with more pronounced polychromy in the fourth century.

The main motif falls within the evolved typology of the combination of circles and squares, which, in association with strongly pronounced *peltae*, result in quadriconic figures[4]: quadrilobal motifs are thus created, free in Room 4 and inscribed in Room 5, which can have for their center, indifferently, either the circle or the square, with the sides placed diagonally as here, or parallel to the walls (Brancato *et al*. 2021, 254-255). The two most precise comparisons for the tessellated floors of Rooms 3 and 4 come from *Africa Proconsularis*: a specimen from Uthina (Ben Mansour 1992-93, 39-41, fig. 1) of the second half of the third century may be related to the mosaic in Room 3 (an orthogonal composition pattern of circles and squares), and a floor from Bulla Regia (Hanoune 1989, 539-542, fig. 24) attested in the hall/cell of a late second-early third century temple building, which has

[4] The geometric pattern corresponds to n. 457 (composition of circles and quadrilobes of non-contiguous pelts) of the Graphic Repertory of the geometric decoration in the ancient mosaic (Darmon, Rebourg 1973).

strong similarities to the mosaic of Room 4 both in syntax and in the use of the same decorative motifs.

Such compositions find their greatest diffusion in the provinces of Africa from the beginning in the Severan age. Beyond, in the middle of the third century, they impose themselves in the western sphere, especially in areas with strong African cultural links such as Sardinia and Spain, but they are also found in Sicily and Calabria, as well as in Northern Italy, albeit not before the fourth century AD (Brancato *et al.* 2021, 254-258). To the same time span seems to belong the decoration of the triclinium (Room 8), distinguished by double-scored knots between pinwheels of *peltae* (Brancato *et al.* 2021, 248-249).

To conclude, attempts at dating on a stylistic basis would seem to place the mosaic production of the Castellito villa in a period between the late second century AD and the first half of the fourth. However, a number of features seem to indicate for the Calatino villa a phase of restructuring of the rooms and their floor plans that can be placed between the end of the second and the early third centuries AD and middle/end of the third century. These are: the predominant white background, the reduced and core colour scales, the absence of chiaroscuro and perspective effects, the simple and redundant decorations and the limited variety of fillers (cruciform rosettes with squared petals, Solomon's knots and circles divided into four quarters and fielded by diagonally opposite colours) (Brancato 2020c; Brancato *et al.* 2021, 259).

L.M.

3. The 3D modeling: reconstructive proposals for architectural structures

The analysis of the data deduced from the planimetric drawing and from the limited remains *in situ* allows us to reconstruct, with limited margins of uncertainty, the plan and the elevation of the walls and roofs of the eastern sector of the Castellito villa in the construction phase of the second half of the third century AD. This contribution proposes a preliminary reconstruction of the structural, functional and aesthetic elements of the building, reproduced in the form of a digital model (Fig. 9) to be considered, as well as on top of its informative purpose, as a framework in continuous evolution and a platform for the simulation and verification of hypotheses. It should be seen not only as a representational image, but as part of the holistic and constructional research. The 3D mode – which can be viewed on Sketchfab (https://skfb.ly/oBYGV) – of the archaeological excavation, obtained through aerial and terrestrial photogrammetry techniques, has been essential to the reconstruction hypotheses (see § 2.2).

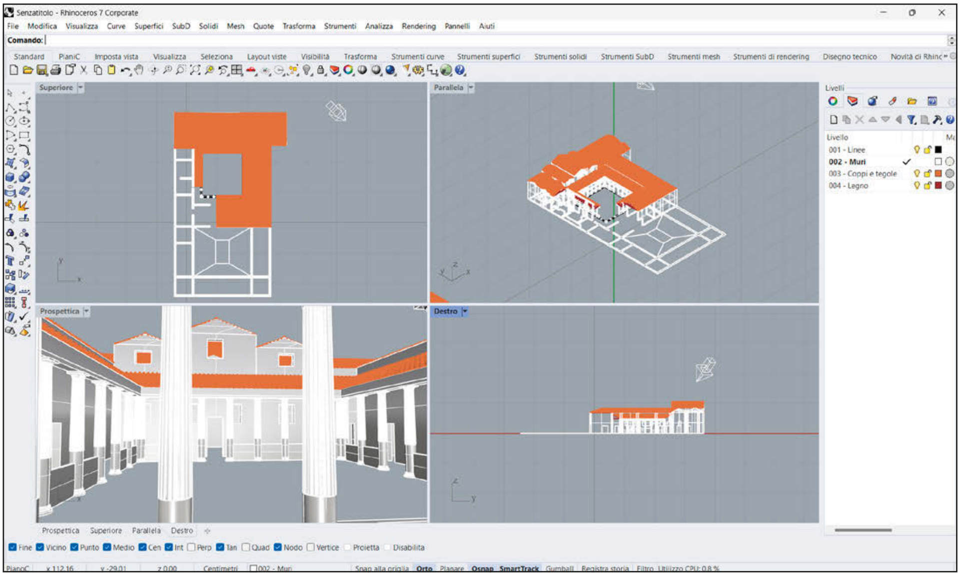

Fig. 9 – Schematic plan of the villa, screenshot of the modelling software used.

Examination of the building technique and wall joins suggests that the construction of this phase was the result of a unified project, based on proportional and symmetrical modules (Fig. 9). To reach this conclusion, it had first been assumed that the design was a rational process and that there is some coincidence between the planned and existing structures, or what remains of them. The original design is then reconstructed by schematising the plans. This simplification is generally accepted, as it is believed that in ancient times architects or master builders used schematic design drawings to convey basic information to the construction site, leaving the definition of details to later stages of construction (Jones 2000, 49-50). That said, the linear unit of measurement identified is the Roman Foot of 29.65 cm, with a building extension in the NS direction of 108 RF, or 72 *cubiti* (1 *cubito* = 1.5 RF). In the EW direction 96 *cubiti* are ascertained. Assuming the size of the extension of the structures towards the W (as found in the NS direction, where no sub-multiples of the identified modulus are considered), the whole area of the villa could be about 140 *cubiti* (210 RF) or 1 and ¾ *actus*.

The investigation carried out on the plan also allows us to draw some general conclusions about the heights of the walls, windows, roofs and upper stories of the villa. In proportion to the area covered, to the size of the rooms and taking the architectural order of the four-sided portico to be about 9 *cubiti* high, the structures could have reached a height of between 20 and 25 *cubiti*, with the reception hall having a double height and a possible upper floor on part of the building.

Although no stairwell was found, the construction of the walls, their thickness (between 0.68 and 0.52 m) and how they are built could support, without further intermediate supports, not only the roof but also a planking on the upper floor. It would be reasonable to envisage an upper level in the complex, but given that the northern sector saw, in the next construction phase, a doubling of the thickness of some of the walls in rooms 2-4, this may have been the case only in part of the complex and not the whole (Fig. 9). Regarding the stairs (Campbell, Tutton 2014, 13-74) and access to this additional level, one does not necessarily have to imagine them in stone, as wood is perfectly possible (Adam 2008, 217-221), the traces of which would only be found on the elevation of the relevant retaining walls. Unfortunately, no remains of the walls are preserved to a useful height.

Similarly, the characteristics of the walls allow us to suggest a clay-tiled wooden truss roof (Adam 2008, 221-230) of the double-pitched capriata type with a pitch of slightly less than 20° (Fig. 10, cfr. Fig. 7). Leaving aside on this occasion the special elements (ridge tiles, chimney pots and corner tiles) and the decorative elements (antefixes), for which no evidence has been found, the roofing system can be defined as 'mixed' or 'hybrid', consisting of flat tiles of the Protocorinthian system and semi-cylindrical tiles of the Laconic system, of which only a few examples are preserved. Some of them can be dated to the early Imperial age, the discovery of which testifies to a continuity of use and reuse from a previous building that should not surprise us[5].

The wall and floor coverings consist mainly of plaster and mosaics, in which the colour white predominates. This prevalence led to the optical amplification of the space and the maximisation of luminosity. The small amount of fragmentary material that has been preserved does not allow us to elaborate even hypothetical restorations of the decorative systems in detail and makes it difficult to make a chronological proposal. However, the stratigraphy of the substrate and the preservation of some painted fragments of the plinth of the wall face in Room 4 could be attributable to a division into monochrome red panels alternating with yellow or white panels, with a glossy and polished pictorial surface (Fig. 10). The reds, the only colours still visible on a preparatory layer of mortar, are generally characterised

[5] The examples of the roofs of the major Roman basilicas with ancient tiles studied by Archbishop Pietro Crostarosa are well-known (Shepherd 2021, 228-230). The temple of *Portunus* in the *Forum Boarium* also reused about a hundred ancient tiles in its roof, datable between the late Republic and the late Antique age (Shepherd 2021). See also: Shepherd 2007, 2015, 2016; Bukowiecki, Pizzo, Volpe 2021.

Fig. 10 – 3D reconstruction of the eastern part of the complex (top); interior of Room 4 seen from the N (bottom).

by iron-based pigments, but the presence of various impurities facilitated their degradation (for more details on the problem of composition, see for example the analyses of plaster mortars carried out by Frizot 1977; Adam, Frizot 1983). In Castellito's case, however, these are mainly attributable to exposure to the weather.

The floor mosaics with geometric compositions differ little in colour, alternating between monochrome milky layers, two-coloured with black and white and three-coloured with the addition of red. Mosaics, as well as decorating the interior reception rooms, also covered the portico. The wings of the portico are 2.11 m wide and have an average length of 19.20 m. They are bordered by six columns on each side with a distance between centres of 1.90 m, enclosed at the corners by two heart-shaped columns or corner pillars. The columns were not fixed to the stylobate blocks by *empolia* but were fastened to them by means of a thick layer of mortar.

We are not able to say whether the columns were made of bricks or of limestone blocks, as is part of the stylobate on which they stood, or whether they were smooth or fluted. What we can say is that they had to be finished with stucco and topped by a wooden architrave, also stuccoed (Fig. 10). Between the intercolumniums it is probable that there were masonry handrails, but unfortunately there remain only a few of the limestone diatonic blocks that supported some of the columns on the N and E sides. No evidence remains as to how the *viridarium* must have been decorated. The lighting and ventilation of the interior spaces could have been provided by windows. These, probably made of wood (Wright 2009, 134-135) like the doors, were open both to the outside and inside of the structure (Webster 1959; Velo-Gala, Garriguet Mata 2017), with a greater exposure to the cooler NE winds. Arranged at a height of more than 2 m above ground level, they were probably narrow and high, to avoid the entrance of birds, rodents and thieves.

C.L.

4. Conclusions

The building complex must certainly have been much more intricate than what is visible today: looting activities and the incomplete publication of past excavations have compromised the possibility of reconstructing the building's appearance. However, on the basis of archaeological, technical and architectural considerations, thanks to the application of digital technologies, it has been possible to digitally restore the *pars dominica*, its rooms paved with geometric mosaics, and the central *viridarium*. Using non-destructive prospecting methods (aerial photogrammetry, fieldwalking survey, architectural relief), precise location with RTK GNSS and spatial legacy data integration in a GIS platform, the villa was re-analyzed in its functional architectural characteristic, and contextualized as a focal point of the rural settlement system (Brancato 2020c). Based on the topographical data obtained from the survey campaign, conducted through the integration of direct and indirect survey techniques, the hypothesized reconstruction of the villa's elevation at its *acme* may be the basis of future research projects and for enhancement actions.

Indeed, when a research project focuses on *disiecta membra*, it must necessarily have as a priority objective not only understanding but also visualizing the past, bridging the gap that separates realities from imagination (Manacorda 2008). Digital technologies are thus important tools not only for quantitative and qualitative archaeological analysis, but they can also contribute to other aspects of research, that is, the essential tasks of reconstructing and communicating (Moscati 2007, 2009). In fact, attempting the reconstruction of Phase II of the Castellito villa imposed a considerable interpretive effort that was facilitated by the GIS analysis of heterogeneous data. Indeed, in cases like this where the archaeological evidence is highly compromised, any reconstructive hypothesis is the result of choices and additions (Barceló 2001; Lock 2003).

However, in the case of Castellito, the 3D modelling of the building, in conjunction with the historical reconstruction process, was an opportunity to reflect on the residual architectural evidence and to address the communication problems posed by a 'marginal' archaeological site. From this perspective, the process of creating the 3D digital reconstruction model can be considered a metaphor for the entire process of knowledge creation in archaeology (De Felice, Sibilano 2010; Limoncelli 2012).

This study sheds light on the great potential in applying digital technologies to gain a new understanding of the Roman villa remains: indeed, the applied workflow – from analysis to synthesis, in the light of the site's history and through different stages of interpretation – and the digital analysis of seemingly meaningless clues have allowed us to propose an organic historical hypothesis for the site until the fourth century at least, which will form the basis of future investigations.

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REFERENCES

Adam J.-P. 2008, *L'arte di costruire presso i Romani. Materiali e tecniche*, Milano, Longanesi.

Adam J.-P., Frizot M. 1983, *Pompéi, étude de dégradation, proposition de restauration*, Paris, CNRS.

Albanese Procelli R.M., Procelli E. 1988-1989, *Ramacca (Catania). Saggi di scavo nelle contrade Castellito e Montagna negli anni 1978, 1981 e 1982*, «Notizie Scavi di Antichità», s. VIII, 42-43, 7-148.

Angiolillo S. 1981, *Mosaici antichi in Italia. Sardinia*, Roma, Libreria dello Stato.

Anichini F., Gattiglia G. 2012, *#MappaOpenData. from web to society. Archaeological open data testing*, in M.L. Gualandi (ed.), *MapPapers 3-II/2012*, Roma, Edizioni Nuova Cultura, 51-56 (http://mappaproject.arch.unipi.it/wp-content/uploads/2011/08/Pre_atti_online3.pdf).

Balmelle C., Blanchard-Lemee M., Christophe J., Darmon J.P., Guimier-Sorbets A.M., Lavagne H., Prudhomme R., Stern H. 1985, *Le décor géométrique de la mosaïque romaine: répertoire graphique et descriptif des compositions linéaires et isotropes*, 1, Paris, Picard.

Balmelle C., Blanchard-Lemée M., Christophe J., Darmon J.P., Guimier-Sorbets A.M., Lavagne H., Raynaud M.P., Stern H. 2002, *Le décor géométrique de la mosaïque romaine: répertoire graphique et descriptifs des décors centres*, 2, Paris, Picard.

Barceló J.A. 2001, *Virtual Reality for archaeological explanation. Beyond "picturesque reconstruction*, «Archeologia e Calcolatori», 12, 221-244 (http://www.archcalc.cnr.it/indice/PDF12/12Barcelo.pdf).

Becatti G. 1961, *Scavi di Ostia IV. Mosaici e pavimenti marmorei*, Roma, Libreria dello Stato.

Ben Mansour S. 1992-1993, *Note sur une mosaïque rouge découverte dans la maison d'industries à Uthina (Oudna)*, «Africa. Fouilles, monuments et collections archéologiques en Tunisie», 11-12, 39-41.

Bezzi A., Bezzi L., Ducke B. 2010, *Computer vision e Structure from Motion, nuove metodologie per la documentazione archeologica tridimensionale: un approccio aperto*, in G. De Felice, M.G. Sibilano (eds.), *ArcheoFOSS. Open Source, Free Software e Open Format nei processi di ricerca archeologica. Atti del V Workshop (Foggia 2010)*, Bari, Edipuglia, 103-111.

Bogdani J. 2020, *Fieldnotes for the development and publication of open standards for the vectorisation of archaeologic and architectonic topographic legacy data*, in J. Bogdani, R. Montalbano, P. Rosati (eds.), *ArcheoFOSS XIV 2020: Open Software, Hardware, Processes, Data and Formats in Archaeological Research. Proceedings of the 14th International Conference*, Oxford, Archeopress, 138-147 (https://www.archaeopress.com/Archaeopress/download/9781803271248).

Brancato R. 2019a, *How to access ancient landscapes? Field survey and legacy data integration for research on Greek and Roman settlement patterns in Eastern Sicily*, «Groma», 4, 1-36 (https://groma.unibo.it/issue-2019/brancato-access-ancient-landscapes).

Brancato R. 2019b, *Nuovi dati sul tracciato della* Catina Agrigentum*: insediamento e viabilità nella Piana di Catania (Sicilia Orientale)*, «Journal of Ancient Topography», 27, 309-340.

Brancato R. 2020a, *Topografia della Piana di Catania*, Roma, Quasar.

Brancato R. 2020b, *Archeologia di un paesaggio marginale: la pianura di Catania prima e dopo le opere della bonifica*, in F. Nicoletti, R. Panvini (eds.), *Archeologia in Sicilia nel secondo dopoguerra*, Palermo, Grafica Saturnia, 125-135.

Brancato R. 2020c, *Il territorio di* Catina *in età imperiale: paesaggio rurale ed economia nella Sicilia romana*, «Atlante Tematico di Topografia Antica», 30, 269-290.

Brancato R., Magro M.T., Manganelli L. 2021, *Indagini archeologiche e topografiche nella villa romana di contrada Castellito di Ramacca (Catania). Risultati preliminari delle ricerche 2019/2020*, «Journal of Ancient Topography», 31, 237-270.

Campana S. 2017, *Drones in archaeology. State-of-the-art and future perspectives*, «Archaeological Prospection», 24, 275-296.

Campbell J.W.P., Tutton M. (eds.) 2014, *Staircases. History, Repair and Conservation*, New York, Routledge.

Cassieri N. 2000, *Pavimenti musivi dal sito di* Tres Tabernae *nell'agro pontino*, in F. Guidobaldi, A. Paribeni (eds.), *Atti del VI Colloquio dell'Associazione Italiana per lo Studio e la Conservazione del Mosaico (Venezia 1999)*, Ravenna, Edizioni del Girasole, 239-252.

Castrorao Barba A. 2016, *Alcune statistiche sulle dinamiche cronologiche degli insediamenti secondari in Italia nella lunga durata tra età romana e Medioevo*, in P. Basso, E. Zanini (eds.), Statio amoena. *Sostare e vivere lungo le strade romane*, Oxford, Archaeopress, 121-128.

Challis K., Forlin P., Kincey M. 2011, *A generic toolkit for the visualization of archaeological features on airborne LiDAR elevation data*, «Archaeological Prospection», 18, 279-289.

Darmon J.P., Rebourg A. 1973, *Répertoire graphique du décor géométrique dans la mosaïque antique*, «Bulletin de l'AIEMA», 4.

De Felice G., Sibilano M.G. 2010, *Strategie di documentazione per la ricerca e la comunicazione archeologica. Il caso di Faragola (Foggia, Italia)*, «Virtual Archaeology Review», 1, 2, 95-99 (https://doi.org/10.4995/var.2010.4696).

Farioli Campanati R. 1975, *Pavimenti musivi di Ravenna paleocristiana*, Ravenna, Longo.

Ferdani F., Demetrescu E., Cavalieri E., Pace G., Lenzi S. 2019, *3D modelling and visualization in field archaeology. From survey to interpretation of the past using digital technologies*, «Groma», 4 (https://doi.org/10.12977/groma26).

Frizot M. 1977, *Mortiers et enduits peints antiques. Etude technique et archéologique*, Centre de Recherches sur les techniques gréco-romaines, 4, Dijon, Université de Dijon.

Grandi M., Guidobaldi F. 2006, *Proposta di classificazione dei cementizi e mosaici omogenei ed eterogenei*, in C. Angelelli (ed.), *Atti dell'XI Colloquio dell'Associazione Italiana per lo Studio e la Conservazione del Mosaico (Ancona 2005)*, Tivoli, Scripta Manent, 31-38.

Hanoune R. 1989, *Bulla Regia (Tunisie)*, «Mélanges de l'École française de Rome. Antiquité», 101, 19, 539-542.

Jones M.W. 2000, *Principles of Roman Architecture*, New Haven/London, Yale University Press.

Kokalj Ž., Oštir K., Zakšek K. 2011, *Application of sky-view factor for the visualization of historic landscape features in lidar-derived relief models*, «Antiquity», 263-273.

Limoncelli M. 2012, *Il restauro virtuale in archeologia*, Roma, Carocci.

Lock G. 2003, *Using Computers in Archaeology: Towards Virtual Pasts*, London-New York, Routledge (https://doi.org/10.4324/9780203451076).

Lopreato P. 1987, *La villa imperiale delle Marignane in Aquileia*, in *Aquileia e Roma. Atti della XVII Settimana di studi aquileiesi (Aquileia 1986)*, Udine, Arti grafiche friulane, 137-149.

Malacrino C.G. 2013, *Architettura e mosaici della villa romana di loc. Larderia a Roggiano Gravina*, in C. Angelelli (ed.), *Atti del XVIII Colloquio dell'Associazione italiana per lo studio e la conservazione del mosaico (Cremona 2012)*, Tivoli, Edizioni Scripta, 473-490.

Manacorda D. 2008, *Lezioni di archeologia*, Roma-Bari, Laterza.

Miele F. 2011, *I rivestimenti parietali e pavimentali ad Alife e nel suo territorio in età romana*, in C. Angelelli (ed.), *Atti del XVI Colloquio dell'Associazione Italiana per lo Studio e la Conservazione del Mosaico (Palermo-Piazza Armerina 2010)*, Tivoli, Edizioni Scripta, 301-314.

Moscati P. (ed.) 2007, *Virtual Museums and Archaeology. The Contribution of the Italian National Research Council*, «Archeologia e Calcolatori», Suppl. 1 (http://www.archcalc.cnr.it/journal/idyear.php?IDyear=2007-01-01&sup=true).

Moscati P. 2009, *Archeologia e musealizzazione virtuale*, in A.L. D'Agata, S. Alaura (eds.), *Quale Futuro per l'Archeologia?*, Roma, Gangemi, 189-200.

Pagliara A. 1997, *Contributo alla sismologia storica siciliana: il terremoto del 21 luglio 365 d.C. nelle fonti antiche e medievali*, in G. Giarrizzo (ed.), *La Sicilia dei terremoti. Lunga durata e dinamiche sociali*, Catania, Maimone, 69-85.

Patanè A. 1997-1998, *Scavi e ricerche a Catania, Licodia Eubea, Grammichele, Ramacca*, «Kokalos», 43-44, 189-195.

Patanè A. 2001, *Contrada Castellito*, in *Itinera. Siti archeologici della Provincia di Catania*, CD-Rom, Palermo, Regione siciliana.

Russo M., Remondino F., Guidi G. 2011, *Principali tecniche e strumenti per il rilievo tridimensionale in ambito archeologico*, «Archeologia e Calcolatori», 22, 169-198 (http://www.archcalc.cnr.it/indice/PDF22/AC_22_Russo_et_al.pdf).

Sfameni C. 2006, *Ville residenziali nell'Italia tardoantica*, Bari, Edipuglia.

Sfameni C. 2019, *Spazi del lavoro e della produzione nelle Ville e in altri contesti abitativi della Sicilia tardoantica: considerazioni a partire da ricerche recenti*, «AMOENITAS», 7, Pisa-Roma, Istituti Editoriali e Poligrafici Internazionali, 83-113.

Shepherd E.J. 2007, *Considerazioni sulla tipologia e diffusione dei laterizi da copertura nell'Italia tardo-repubblicana*, «Bullettino della Commissione Archeologica Comunale di Roma», 98, 55-88.

Shepherd E.J. 2015, *Tegole piane di età romana: una tipologia influenzata dalle culture «locali», una diffusione stimolata dall'espansione militare*, «Archeologia dell'Architettura», 20, 120-132.

Shepherd E.J. 2016, *Tegole di copertura in età romana: questioni di forma, posa in opera e impiego*, «Costruire in laterizio», 168, 54-59.

Shepherd E.J. 2021, *Lunga durata o reimpiego filologico? Storia delle tegole del Tempio di Portuno*, in E. Bukowiecki, A. Pizzo, R. Volpe (eds.), *Demolire, riciclare, reinventare. La lunga vita e l'eredità del laterizio romano nella storia dell'architettura*, *III Convegno Internazionale "Laterizio" (Roma 2019)*, Roma, Quasar, 225-242.

Spigo U. 1982-1983, *Note preliminari sugli insediamenti di età imperiale romana nei territori di Lentini, Carlentini, Ramacca, Caltagirone, Grammichele*, «Kokalos», 28-29, 341-344.

Spigo U. 1997, *Prime considerazioni sui mosaici geometrici del complesso termale di Bagnoli S. Gregorio a Capo d'Orlando*, in *Atti del IV Colloquio dell'Associazione italiana per lo studio e la conservazione del mosaico (Palermo 1996)*, Ravenna, Edizioni del Girasole, 259-272.

Tigano G. (ed.) 2008, *Terme Vigliatore – S. Biagio: nuove ricerche nella villa romana (2003-2005)*, Palermo, Regione siciliana.

Uggeri G. 2004, *La viabilità della Sicilia in età romana*, Galatina, Congedo Editore.

Velo-Gala A., Garriguet Mata J.A. 2017, *Roman window glass: An approach to its study through iconography*, «Lucentum», 36, 159-176.

Webster G. 1959, *Roman windows and grilles*, «Antiquity», 33, 129, 10-14.

Wilson R.J.A. 1990, *Sicily under the Roman Empire: The Archaeology of a Roman Province, 36 B.C.-A.D. 535*, Warminster, Wiltshire, Aris and Phillips.

Wilson R.J.A. 2019, *Scavi alla villa romana di Gerace, Sicilia: risultati della campagna 2016*, «Cronache di Archeologia», 28, 299-346.

Wright G.R.H. 2009, *Ancient Building Technology*, 3, 1, Leiden, Brill.

ABSTRACT

This paper presents the results of the research undertaken through a series of on-site surveys and studies (2019-2022) of the site of Castellito di Ramacca (Catania, Sicily). The site, located on the top of a low hill (106 msl), was partly excavated in the late 20th century and interpreted as a Roman rural building, possibly with a special function (road station). Its name is also attested in ancient sources (Capitoniana). The site was re-evaluated using various non-destructive prospecting methods (aerial photogrammetry, fieldwalking survey, architectural recording), precise location with RTK GNSS and integration of the legacy data in GIS. This approach confirmed a new addition to the already known villa complex and contextualized it as a focal point of the rural settlement system. Based on the topographical data obtained from the survey campaign, conducted by integrating of different techniques, we propose a reconstruction of the villa's elevation at its peak in Late Antiquity. This study illustrates the great potential of applying digital technologies for a new understanding of Roman villa remains.

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MULTISPECTRAL AND HIGH-RESOLUTION IMAGES AS SOURCES FOR ARCHAEOLOGICAL SURVEYS. NEW DATA FROM IRAQI KURDISTAN

1. Introduction

Remote Sensing (RS) is a well-established resource for archaeological research. The first RS applications to archaeology with the first aerial photos were conducted at the end of the 19th century in Europe and during the early decades of the 20th century in the Near East (Poidebard 1934). With the rise of satellite imagery, the remote observation of the ground could be performed at a completely different scale. The relatively low spatial resolution of the first sensors hampered the possibility of identifying small archaeological features but gave an incredible boost to approaching the wider landscape framework and relations between different sites. The availability of commercial satellites equipped with sensors, whose pixel size was less than ten meters, subsequentely also allowed the identification of sites that were previously undetectable. The appearance of multispectral sensors then allowed us to see what was invisible, much more deeply than was possible using analogue infrared films.

The recent fast development of software, data access and artificial intelligence applications are again revolutionizing RS applications for archaeology, with a worldwide impact for the entire discipline (Forte, Campana 2016). The availability of new archival material opened the way to new discoveries as well: the declassification of military data such as the CORONA imagery offered additional resources that are particularly important for landscape archaeology applications, especially in the Near East area, as their acquisition period dates back to the 1960s, before the massive urban development of the second half of the 20th century (Casana, Cothren 2013). Among the most notable advances concerning RS data processing, the most important is cloud computing applied to geospatial products: large datasets containing hundreds of images or other types of data can be processed by users who can rely on cloud infrastructures. This computational power allows analysis at an unprecedented scale. Google Earth Engine (GEE) is a popular and free online resource for geospatial processing (Gorelick *et al.* 2017). GEE can be used to create and analyse RS big data, producing for instance mosaicked images or land use analysis using decades of satellite images. Although the spatial resolution of the available datasets is usually quite low for the immediate identification of small-sized archaeological features on the ground, GEE can be succesfully used to retrieve other useful information, such as the level of moisture in the soil, and to identify the larger sites. Its use is also spreading within the archaeological community with applications in the Near East area such as in Jordan (Liss *et al.* 2017), Syria (Agapiou 2020) and Iraqi Kurdistan as well (Titolo 2021).

During recent decades, archaeological missions in the area of ancient North Mesopotamia, which currently belongs to the Iraqi Kurdistan autonomous region, have increased in number and scope, helping to reveal a known but previously underestimated archaeological heritage. Several international archaeological missions are active in this area; most of them rely on RS as a primary source for site identification and for reconstructing the ancient landscape (Morandi 2016; Pfälzner *et al.* 2016; Kolinski 2018; Ur *et al.* 2021). Other examples of RS applications in Kurdistan have been in the Sulaymaniyah province (Altaweeel, Squitieri 2019), in Erbil province (Soroush *et al.* 2020), the Sirwan region (Laugier, Casana 2021; Laugier *et al.* 2022), on the Kona Makhmūr site (S of Erbil: Starková 2020) as well as in the Navkur Plain (Pirowski *et al.* 2021) and on the Khinis site (Malinverni *et al.* 2017). The last two locations are situated within the area surveyed by the Land of Nineveh Archaeological Project (LoNAP) conducted by the University of Udine since 2012.

R.V.

2. Materials and methods

2.1 *The geomorphological and archaeological landscape*

The Navkur Plain (muddy plain in local Kurmanji Kurdish) covers an area of almost 1400 km². It is characterized by fertile clayey soil, delimited by the Zagros mountain range to the N and E, while the Jebel Bardarash and Jebel Maqloub mountains border it to the W and S, respectively. The plain slopes gently both along the NS and EW axis; it is crossed by several watercourses, most of which are seasonal, with water flowing only during winter and early spring with some exceptions like the Nahr al-Khazir and the Gomel Su, two perennial rivers that deeply cut the plain. The availability of water is guaranteed also by regular rainfall, that ranges between 300 and 600 mm annually, as well as by the several karst springs that occur in the typical hilly landscape of the Zagros foothills (Wirth 1962, abb. 9-10; Forti *et al.* 2021). This variegated landscape therefore offered ideal conditions for human communities that settled in seasonal camps and/or shelters and, since the so-called Neolithic Revolution (c. 10,000 BCE), in permanent settlements. This explains the area's importance for archaeological projects focusing on a number of fundamental themes of the human past, ranging from the study of the Upper Palaeolithic-Neolithic transition to the exploitation of the countryside by large empires that dominated the area in historical periods. Regional survey projects have amply demonstrated the plain's archaeological importance, thanks to the discovery of

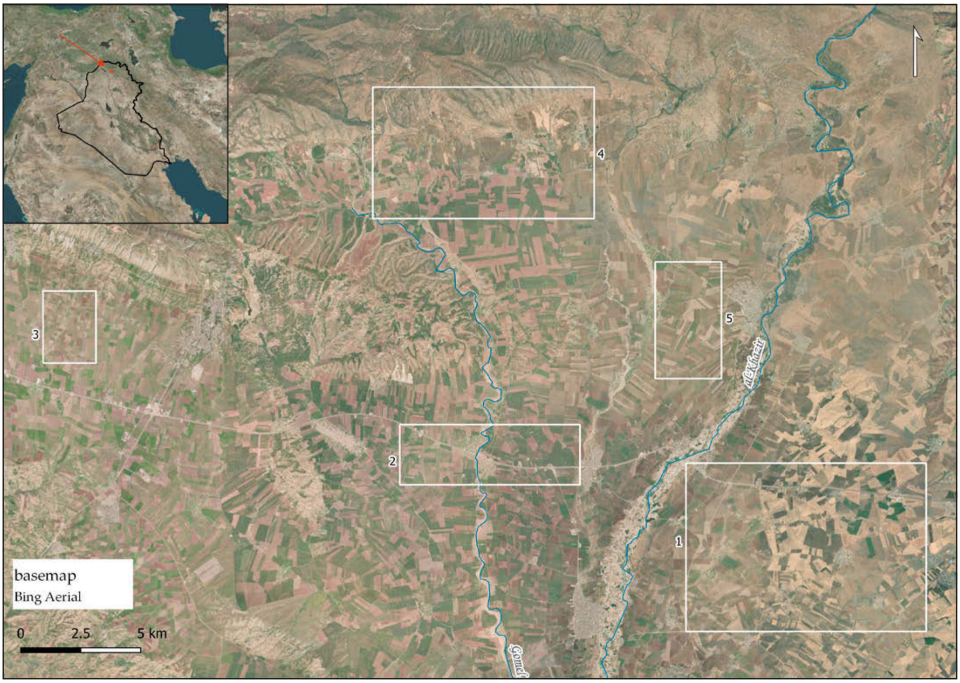

Fig. 1 – Localization of the five surveyed areas in the northern part of Iraq (autonomous Kurdistan region).

a number of settlements dated to prehistoric and historical epochs (Morandi Bonacossi, Iamoni 2015; Koliński 2018). Despite these excellent results, the reconnaissance of the ancient settlements remains a complicated task, in the light of modern settlement and the intensive exploitation of the fertile soils for agricultural purposes. Long settled areas are often more easily recognisable when they pertain to historical epochs. In these cases, the decay of mudbrick structures, such as private houses and public buildings, creates typical mounded sites, known as 'tells' (Arabic) or 'gird' (Kurdish). Settlements characterised by short temporal occupation sequences – the likely consequence of a higher degree of mobility and the associated greater fragility of less permanent housing/residential structures – have given rise to low mounded sites which are less visible in the plain (Wilkinson 2003, 48; Wilkinson, Ur, Hritz 2013, 37-40).

This occurs frequently in prehistoric times, when societies tend to move more easily, but it is also possible that similar phenomena may have taken place in more recent epochs, especially if characterised by socio-political instability. As a result, the investigation of the ancient landscape may miss substantial pieces: in particular, the reconstruction of the earliest phase of human presence, e.g. the Neolithic, when settlements tend to be small and change location over time (Akkermans 2013), may be substantially inaccurate (Nieuwenhuyse, Wilkinson 2008, 271) if adequate methods are not developed to solve these difficulties.

M.I.

2.2 *Target areas (2021-2022)*

Within the larger LoNAP survey area, five smaller target areas (1-5) have been selected for the analysis (Fig. 1): area 1 (about 70 km^2) is close to the Asingeran site and E of the River al-Khazir; area 2 (about 19 km^2) crosses the River Gomel; area 3 (about 7 km^2) is located between 'Baadhrah' and Ash Shaykhan; area 4 (about 50 km^2) covers part of the piedmont area S of the hills that border the Atrush valley to the S; and area 5 (about 13 km^2) is W of the village of Qasrok. They are all situated in the wider Navkur Plain for an overall area of about 159 km^2. The five target areas represent the main morphological characteristics, such as flat regions (3, 4), regions crossing or in between important waterways (2, 5) and regions close to the first high hills that precede the Zagros mountain range (4). While some known sites already surveyed by the LoNAP mission were located in areas 1, 2 and 4, areas 3 and 5 were blank.

R.V.

2.3 *Use of Google Earth Engine for archaeological purposes*

The retrieval and processing of satellite imagery used for this study was carried out with GEE. Within the GEE environment, three main datasets were selected, acquired by three different platforms: Landsat 5 (https://www.usgs.gov/landsat-missions/landsat-5), Landsat 7 (https://www.usgs.gov/landsat-missions/landsat-7) and Sentinel-2 (https://sentinel.esa.int/web/sentinel/missions/sentinel-2). The characteristics of the Landsat multispectral sensors are similar, with an increased spatial resolution for Landsat 7 (Landsat 5: radiometric resolution 0.45-2.35 μm; spatial resolution 30 m reflective, 120 m thermal. Landsat 7: radiometric resolution 0.45-2.35 μm; spatial resolution 15 m panchromatic, 30 m reflective, 60 m thermal). Both of them have seven bands (B1: blue; B2: green; B3: red; B4: near-infrared; B5: short-wave infrared; B6: thermal; B7: mid-infrared), with an additional band (B8: panchromatic) for Landsat 7. Sentinel-2 multispectral sensor is different (radiometric resolution: 0.443-2.19 μm; spatial resolution: from 10 to 60 m) and delivers thirteen bands (B1: ultra blue; B2: blue; B3: green; B4: red; B5- B6- B7- B8: visible and near infrared; B9- B10- B11- B12: short-wave infrared).

An additional dataset (MODIS Combined 16-Days NDWI) acquired by the Terra-Aqua platforms, was used to estimate in the investigated area the

Normalized Difference Water Index (NDWI) value, which shows the quantity of moisture on vegetation and the ground. As archaeological features are usually more visible when the moisture level in the ground is higher, the NDWI trend suggested the selection of images that were acquired within the period January-April, that partially coincides with the ‘wet’ season in Kurdistan. The average NDWI value was computed for the time interval 2012-2021, that also coincides with the beginning of LoNAP surveys, to assess the trend over a decade.

The added value of GEE is that it is not only an image viewer but also allows for image processing, exploiting the power of cloud computing and making possible computations on large datasets that would otherwise require enormous hardware resources. This allowed the adoption of a multitemporal approach that proved to be particularly efficient for archaeological purposes (Valente *et al*. 2022). Instead of selecting single images from a certain dataset, an entire image stack was chosen within the previously stated seasonal limits. An additional chronological boundary was set: for the Landsat datasets two decades were selected, respectively 1984-1994 for Landsat 5 and 2000-2010 for Landsat 7, while for the more recent Sentinel-2 dataset the chosen interval was 2018-2021. Every stack was further filtered excluding images with high cloud coverage.

The filtered datasets had different composition: 110 images for the Landsat 5 1984-1994 collection, 132 images for the Landsat 7 2000-2010 collection and 31 images for the Sentinel-2 2018-2021 collection. The lower number of images of the last dataset is due to the limited period of acquisition compared to the Landsat collections. Thus, a final output was obtained as the result of a median function applied to every pixel, for each band independently. This way, seasonal visibility of sites was enhanced, limiting constraints due to field conditions such as the presence of crops covering the ground. An additional output was obtained from Sentinel-2 by applying a ratio index ($I_{B4,B8}$= B4/(B4-B8) that uses bands 4 and 8, improving the visibility of anomalies in the image. A pan-sharpening with the panchromatic band was also performed on the Landsat outputs, to increase the spatial resolution from 30 m to 15 m; this operation was not performed on the Sentinel output as the native spatial resolution of some of its bands was already 10 m. All the previous operations were carried out within the GEE interface and through its JavaScript console.

The generated outputs were then uploaded in QGIS to be managed along with the existent spatial data and visualized in false colours to enhance the anomalies that could correspond to unknown archaeological sites. At first, the appearance of known archaeological sites, whose location was stored in a .SHP file, was checked on the new outputs. All the available bands were initially observed: nevertheless, band 5 (that corresponds to shortwave infrared) proved to be more effective with Landsat outputs, while the RGB range,

Fig. 2 – Comparison of archival satellite images of surveyed sites; imagery retrieved using Google Earth Pro.

band 4 (red) and band 8 (near infrared) were found more effective with the Sentinel data. This last output was visualized also with the $I_{B4,B8}$ index applied.

Based on the previous surveys carried out in the same region, the most frequent types of sites in the Navkur Plain are: i) *tells*, i.e., artificial mounds that usually correspond to the principal settlements; ii) flat sites, i.e., sites with no or low elevation, often characterized by lighter coloration of the soil; iii) sites with structures. The latter type can have some variants, spanning from human settlements with remains of residential structures to simple pastoral enclosures. As a general rule, most of the flat sites appear on multispectral satellite images as clearly identifiable neat and round traces, whose colour is different from the surrounding soil; this is due to the different composition of the anthropogenic soil compared to the fertile one. The new visually identified anomalies were recorded in another .SHP files: 42 anomalies were identified in 2021 and 59 in 2022, for a total of 101. This number includes both anomalies that are very similar to the already known sites, and others less evident that would have been subsequently checked on the ground.

The 2022 survey used the same methodology and tools tested in the previous year, increasing however the use of high-resolution imagery freely available through web services such as Google Earth Pro and Bing Maps. These services offer little customization options but share high-resolution images for free, an important aspect when dealing with large areas and limited funds. This way, it was possible to integrate the information coming from the multispectral processed images and the available panchromatic high-resolution images that allow for a better identification of features on the ground. In addition to multispectral images, recent and archival high-resolution imagery was retrieved using Google Earth Pro and compared to observe the identified regions in different images, since their appearance can change substantially depending on the acquisition period (Fig. 2). This approach aimed to verify the limits of the applicability of the previously tested method on the different natural environments of area 4. In fact, in proximity to the rocky hills S of the Zagros mountain range the fertile soil of the plain progressively ends. Due to different environmental conditions, ancient human settlements were more likely to have a different appearance to those in lower lands, or at least to have left different traces in the soil. The first preliminary observations of this area in 2021 on multispectral images revealed less clear results that required a more careful approach.

R.V.

2.4 *Extraction of spectral signatures*

GEE allowed also to extract spectral signatures given a sampling area. The Sentinel-2 median was selected for the spectral signature extraction due to its better spatial resolution. For this study, a 50×50 m sampling area was used for every region corresponding to an identified anomaly: the pixels included within this area were averaged and the corresponding spectral profile was automatically plotted by GEE. As references, also the average spectral signature of areas identified as fields with no archaeological features and the average spectral signature of a selection of known sites were also plotted on the same chart.

R.V.

2.5 *Unsupervised classification and analysis of spectral signatures*

The spectral signatures extracted from the Sentinel-2 dataset were subsequently analysed performing unsupervised statistical classification. Four well-established unsupervised approaches were tested: hierarchical clustering, with the minimum-variance linkage criterion (Ward 1963), k-means (MacQueen 1967), fuzzy c-means (Bezdek 1981) and self-organizing map (SOM) (Kohonen 1982; Maset *et al.* 2015). Classification was performed in Python environment (https://scikit-learn.org/stable/) identifying two clusters. The label for each cluster was then assigned according to its representative element: the one closest to the average spectral signature of already known LoNAP sites represents the 'site' class, whereas the other cluster was identified

Fig. 3 – Localization of surveyed regions over the five areas and results.

as that one containing anomalies with ‘no archaeological sites’, according to the algorithm. Three datasets were created and separately analysed: spectral signatures of sites surveyed in 2021, in 2022, and a set comprising anomalies detected in both 2021 and 2022, so as to better assess the precise results given the different natural environments of targeted areas.

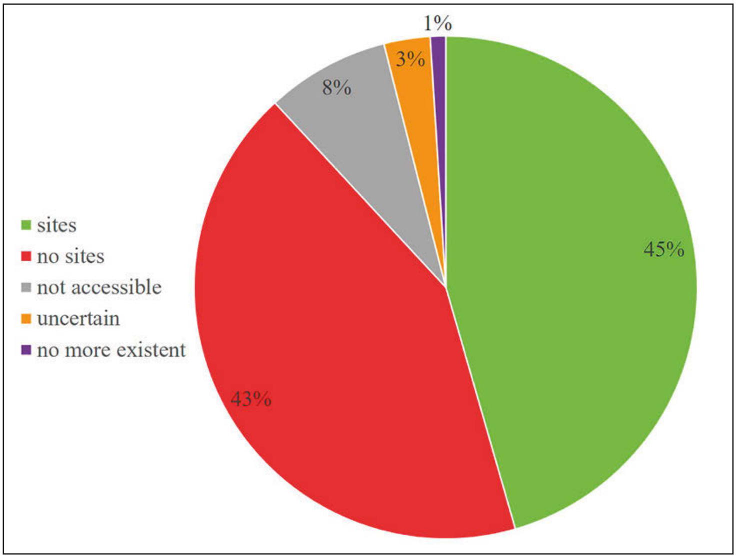

Fig. 4 – Results of 2021-2022 surveys from a total of 101 surveyed regions.

E.M.

2.6 *Ground-truthing assessment*

In order to assess the results of the remote analyses, field surveys were planned. To speed up the fieldwork, the QField app was used to display in real time the position of the team, composed of three to five members, and the locations of the investigated regions (https://qfield.org/). Areas 1, 2 and 3 were surveyed over six days in September and October 2021, while areas 4 and 5 were surveyed over five days in September 2022. In 2022 an additional day was necessary to survey site 426, due to its position on the top of a rocky hill (elevation: 900 m asl). Surface finds, when present, were collected; the subsequent analysis of potsherds also provided preliminary information about the chronology of the surveyed sites, collecting important data for future work on the settlement structure in the Navkur region.

R.V.

3. Results

The 2021-2022 surveys checked on the ground a total number of 101 regions. Eight of these could not be verified because fields were cultivated or because of the presence of fences. Three regions were classified as 'uncertain', because the presence of anthropic material was too scarce to determine a site with confidence, while one single case was a 'disappeared site': a stone enclosure visible in satellite images that had been levelled and only scattered stones were identified on the ground. Forty-three regions did not yield any trace of ancient human presence, while forty-six regions were classified as 'sites' (Fig. 3). The nature of these sites is diverse: two areas were identified as 'ceramic clusters', twelve as *tells*, seventeen as flat sites, four as settlements on rocky hills, five as pastoral structures, five as isolated cemeteries, one as an identified structure (Fig. 4).

With regard to an assessment of the output generated from GEE, both Landsat and Sentinel images gave good results for the identification of new sites. On one hand, Landsat images, that were generated with datasets acquired during the 1985-1995 and 2000-2010 periods, were useful because the landscape they recorded was less urbanized than the contemporary one. On the other, their effectiveness for the identification of new sites was limited by their relatively low spatial resolution. The Sentinel-2 outputs compensated for this constraint with their higher spatial resolution (10 m), allowing identification of smaller sites as well.

A further result achieved by the use of multispectral images is the better identification of site clusters. Potsherds scattered over a large area without any visible discontinuity in their surface distribution are usually related to a single site. This may be true, but the presence of distinct and smaller settlements, indistinguishable with regard to the dispersion of potsherds, may also occur. The use of multispectral images allows better identification of differences in soil, even when these cannot be correctly assessed in the field.

The automatic classification of spectral signatures provided the results summarized in Tab. 1.

Overall, the best performances were reached by k-means and SOM, whereas the hierarchical clustering method appears not to be suitable for this application. Better results were achieved for the 2021 dataset, with a promising overall accuracy of 74% provided by SOM. This corresponds to 12 actual sites correctly identified, and 17 regions that the algorithm correctly classified as 'no site'. On the other hand, performance decreased for the 2022 dataset, with an overall accuracy of 64% achieved by k-means and fuzzy c-means,

	hierarchical clustering	*k-means*	*fuzzy c-means*	SOM
2021	54%	69%	67%	74%
2022	58%	64%	64%	60%
2021 + 2022	53%	60%	57%	57%

Tab. 1 – Overall accuracy provided by the tested algorithms, computed as the ratio of correctly classified sites to the total number of regions analysed.

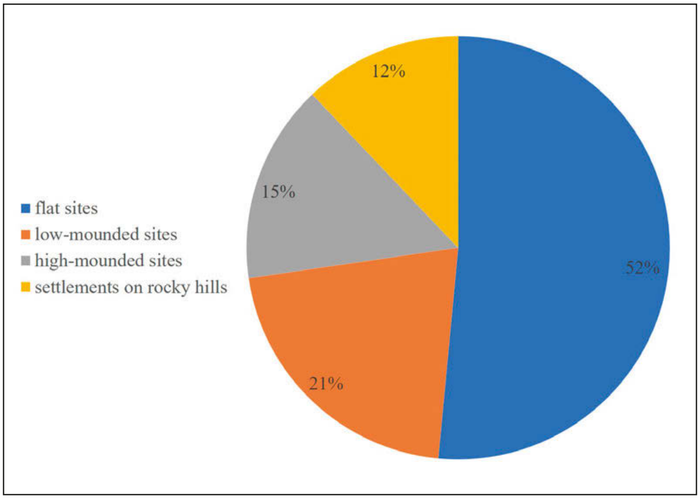

Fig. 5 – Distribution of settlement types among the new sites found: more than half are flat sites on plains, the most difficult type to be detect by RS.

whereas only 60% of the analysed regions were correctly classified by SOM, with 10 actual sites labelled as 'no site' and 10 regions erroneously identified by the algorithm as archaeological sites. No advantages were obtained by jointly processing the spectral signatures of the regions investigated in 2021 and 2022, showing that the different natural environments of the targeted areas affects their spectral signatures, making automatic classification more challenging.

R.V., E.M.

4. Discussion

Most of the new sites (seventeen) identified are flat sites, and this could be expected because sites with elevation are obviously easier to recognize both on RS sources (images but also digital elevation models) and during on-ground surveys. Therefore, most of the sites with elevation had already been discovered in the past LoNAP campaigns. However, the overall number of twelve *tells* identified in 2021 and 2022 is relevant as well: these can be further divided into low-mounded (seven sites) and high-mounded (five sites), depending on their elevation. It is worth noticing that four of five high-mounded tells are located in area 4, and this concentration could be partially explained by the difficult of identifying these sites on the ground in non-plain contexts (Fig. 5).

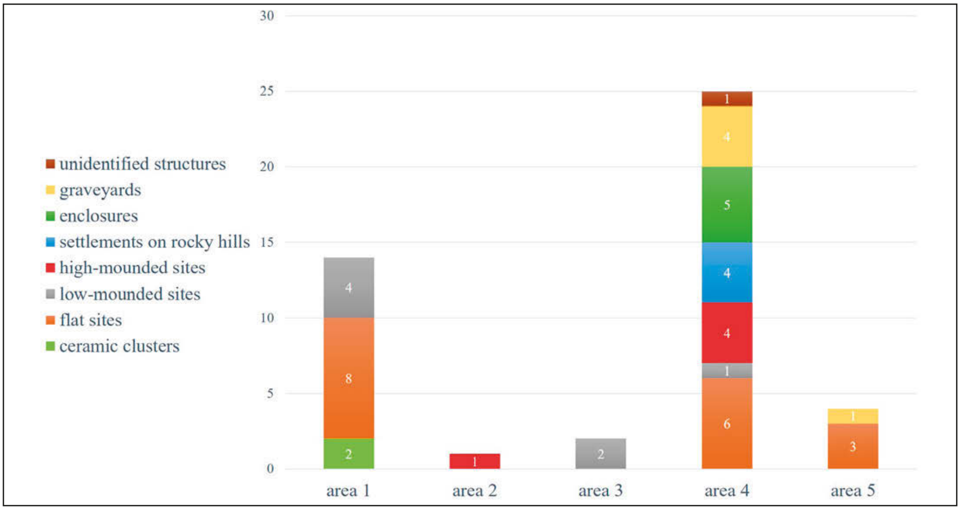

Fig. 6 – Distribution of site types per surveyed area; a marked pre-eminence in number and variety is visible in area 4.

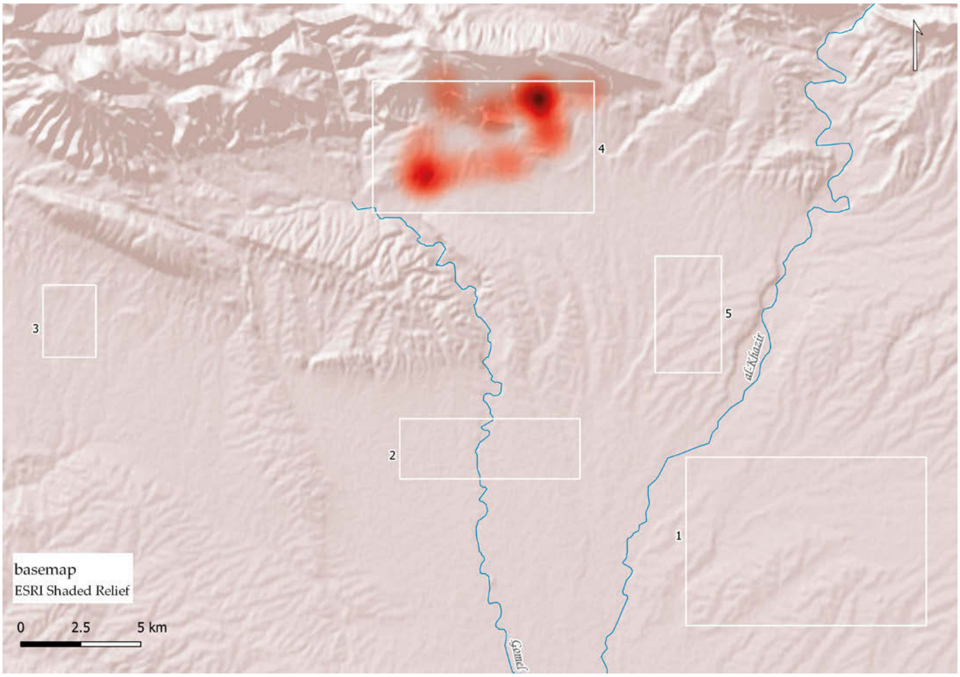

Fig. 7 – Heatmap distribution of new sites with visible remains of standing or collapsed structures; an evident concentration is visible in area 4.

A further analysis of site distribution reveals that area 4, surveyed in 2022, has the highest number of archaeological features (25) followed by area 1, surveyed in 2021, with 14 features; these two areas together yielded the 85% of the overall number of sites found during the two-year survey. Area 4 has also the greatest variety of archaeological features: except for a ceramic cluster, every other type of site was identified (flat sites, low-mounded sites, high-mounded sites, settlements on rocky hills, enclosures, graveyards, unidentified structures) (Fig. 6). This partly depends on the size of the survey area (50 km^2), but also on the peculiarity of this territory at the borders of the Navkur Plain; in comparison in area 1, which is the largest area investigated (70 km^2), only three typologies of sites were found (ceramic clusters, low-mounded and high-mounded sites).

The chronology of the surveyed sites is another noteworthy aspect: they range from the earliest period of stable human presence in the area, i.e., the Pottery Neolithic – c. 7000-4000 BCE – to the most recent one (Ottoman period). This demonstrates the possibility to intercept traces of ancient communities characterized by evanescent archaeological evidence (simple mud architecture) to the most solid remains of ancient buildings with stone walls/structures.

An apparent difference between the 2021 and 2022 field discoveries is that many sites surveyed in 2022 had visible remains of structures variously preserved or pebble heaps, that probably resulted from collapsed structures. Visible structures were located only in sites within area 4, the one closer to the rocky hills (Fig. 7). The morphology distribution of sites with visible structures is very homogeneous: 25% are flat sites, 25% are enclosures, 20% are high-mounded sites and 20% are settlements on hills (the remaining 10% are equally divided between low-mounded sites and the single unidentified structure). Some of these sites yielded a very small number of potsherds, such as sites 411 and 416, despite the many visible structures – suggesting a different nature of the settlements located in the piedmont area compared to those in the plain. A remarkable example is site 399 (Fig. 2): despite the remains of structures clearly visible on a satellite image, accessed via Google Earth Pro and acquired in March 2012, the presence on the ground of heaps of pebbles and the classification of its spectral signature as a true positive, no surface finds were individuated. In this particular case it was considered a site, i.e. a location with past human traces, in view of the remains visible on the archival satellite image, but its chronology remains uncertain. Although the presence of surface potsherds is normally connected with settlements or ceramic clusters, pottery fragments have also been found in proximity of two enclosures (sites 426 and 428) and a graveyard (site 249) that is likely to be a *tell* later converted into a burial place.

The combined use of medium resolution multispectral images and high-resolution panchromatic images was successful, in particular with regard to the piedmont area because of a higher presence of visible structures on the ground and the different composition of soil compared to the fertile land of the plain. The use of high-resolution images is less crucial in relatively flat and cultivated contexts, because most of the flat sites do not show any visible permanent features except for a different colour, whose visibility depends on the surface conditions. On the contrary, they are fundamental where the soil differences are not clearly distinguishable and where surface remains are still preserved; a number of sites surveyed in 2022 were preliminarily identified only on high-resolution panchromatic images, since they were not clear on multispectral images.

While the analysis of spectral signatures proved to be very effective within the plain, its application in the piedmont area revealed some constraints that must be taken into account to correctly interpret the results. Some settlements or structures are located in places where the amount of fertile soil is very low or nearly zero. Moreover, the steep profile prevented any significant accumulation of anthropogenic soil because of natural erosion. For the extraction of spectral signatures, the method presented here uses a sampling area of 50×50 m that works well with the flat sites of the plain, because the frequent morphology of distribution of anthropogenic soil is circular, with a central core that gradually fades outward. When the sample area is centred on the core, most of the pixels that are included within the area cover anthropogenic soil. On the contrary, in hilly contexts most of the sampled soil is natural, partly because of the already mentioned sedimentary process and partly because of the differences in the nature of settlements. Preliminary analysis suggests that settlements here had a scattered distribution of structures rather than a central core; this is due to the fact that inhabitants had to adapt to the different environment, taking advantage of those areas where building was easier. In this challenging context, the future use of a more sophisticated artificial intelligence algorithm for analysis of the multispectral images and the spectral signatures could possibly bring further advantages.

R.V., E.M., M.I.

5. Conclusions

The two-year testing of the use of RS sources and cloud computing tools for the identification of new archaeological sites in the area of the Navkur Plain has yielded interesting results. An overall number of 46 new sites (considering also two ceramic clusters) was found using RS sources within an already surveyed area, proving the advantages of the application of these methods also to areas where archaeological sites are already known. The better spatial resolution of Sentinel-2 than Landsat datasets allowed us to use its products to identify also small and medium-sized ancient settlements that are hardly visible on Landsat images. Small isolated archaeological features still require the use of high-resolution or aerial images, but RS-based archaeological surveys can rely on multispectral medium-resolution imagery for the identification of new settlements. The presented method was successfully tested on both plain and piedmont areas. On rocky hills, or generally when the presence of fertile and anthropogenic soil decreases, high-resolution images are still crucial in order to identify archaeological features.

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REFERENCES

Agapiou A. 2020, *Detecting looting activity through earth observation multi-temporal analysis over the archaeological site of Apamea (Syria) during 2011-2012*, «Journal of Computer Applications in Archaeology», 3, 1, 219-237.

Akkermans P.M.M.G. 2013, *Living space. Temporality and community segmentation: Interpreting Late Neolithic settlement in Northern Syria*, in O.P. Nieuwenhuyse, R. Bernbeck, P.M.M.G. Akkermans, J. Rogasch (eds.), *The Late Neolithic of Upper Mesopotamia*, Turnhout, Brepols, 63-75.

Altaweel M., Squitieri A. 2019, *Finding a relatively flat archaeological site with minimal ceramics: A case study from Iraqi Kurdistan*, «Journal of Field Archaeology», 44, 8, 523-537.

Bezdek J.C. 1981, *Pattern Recognition with Fuzzy Objective Function Algorithms*, New York-London, Plenum Press.

Casana J., Cothren J. 2013, *The CORONA Atlas Project: Orthorectification of CORONA satellite imagery and regional-scale archaeological exploration in the Near East*, in D.C. Comer, M.J. Harrower (eds.), *Mapping Archaeological Landscapes from Space*, New York, Springer, 33-43.

Forte M., Campana S. 2016, *Digital Methods and Remote Sensing in Archaeology. Archaeology in the Age of Sensing*, Springer, Cham.

Forti L., Perego A., Brandolini F., Mariani G.S., Zebari M., Nicoli K., Regattieri E., Barbaro C.C., Bonacossi D.M., Qasim H.A., Cremaschi M., Zerboni A. 2021, *Geomorphology of the North-Western Kurdistan region of Iraq: Landscapes of the Zagros Mountains drained by the Tigris and Great Zab Rivers*, «Journal of Maps», 17, 2, 225-236.

Gorelick N., Hancher M., Dixon M., Ilyushchenko S., Thau D., Moore R. 2017, *Google Earth Engine: Planetary-scale geospatial analysis for everyone*, «Remote Sensing of Environment», 202, 18-27 (https://linkinghub.elsevier.com/retrieve/pii/S0034425717302900).

Iamoni M., Qasim H.A. 2021, *Asingeran, a Neolithic and Chalcolithic "Iceberg" in Northern Mesopotamia*, «Origini», 43, 9-34.

Kohonen T. 1982, *Self-organized formation of topologically correct feature maps*, «Biological Cybernetics», 43, 1, 59-69.

Kolinski R. 2018, *An archaeological reconnaissance in the Greater Zab Area of the Iraqi Kurdistan (UGZAR) 2012-2015*, in R. Salisbury, R.B. Salisbury, F. Höflmayer, T. Bürge (eds.), *Proceedings of the 10th International Congress on the Archaeology of the Ancient Near East; Volume 2: Prehistoric and Historical Landscapes & Settlement Patterns (Wien 2016)*, Wiesbaden, Harrassowitz Verlag, 13-26.

Laugier E.J., Abdullatif N., Glatz C. 2022, *Embedding the remote sensing monitoring of archaeological site damage at the local level: Results from the "Archaeological practice and heritage protection in the Kurdistan Region of Iraq" project*, «PLOS ONE», 17, 6, e0269796 (https://doi.org/10.1371/journal.pone.0269796).

Laugier E.J., Casana J. 2021, *Integrating satellite, UAV, and ground-based remote sensing in archaeology: An exploration of pre-modern land use in Northeastern Iraq*, «Remote Sensing», 13, 24, 5119 (https://www.mdpi.com/2072-4292/13/24/5119).

Liss B., Howland M.D., Levy T.E. 2017, *Testing Google Earth engine for the automatic identification and vectorization of archaeological features: A case study from Faynan, Jordan*, «Journal of Archaeological Science: Reports», 15, 299-304 (https://linkinghub.elsevier.com/retrieve/pii/S2352409X16308082).

MacQueen J. 1967, *Some methods for classification and analysis of multivariate observations*, in L.M. Le Cam, J. Neyman (eds.), *Proceedings of the Fifth Berkley Symposium on Mathematical Statistics and Probability*, 1, Berkeley, University of California, 281-297.

Malinverni E.S., Pierdicca R., Bozzi C.A., Colosi F., Orazi R. 2017, *Analysis and processing of Nadir and Stereo VHR Pleiadés images for 3D mapping and planning the land of Nineveh, Iraqi Kurdistan*, «Geosciences», 7, 80 (https://doi.org/10.3390/geosciences7030080).

Maset E., Carniel R., Crosilla F. 2015, *Unsupervised classification of raw full-waveform airborne lidar data by self organizing maps*, in V. Murino, E. Puppo (eds.), *Image Analysis and Processing - ICIAP 2015 (Genoa 2015)*, Springer, Cham, 69-72 (https://doi.org/10.1007/978-3-319-23231-7_6).

Morandi Bonacossi D. 2016, *The Land of Niniveh Archaeological Project. Assyrian settlement in the Niniveh hinterland: A view from the centre*, in J. MacGinnis, D. Wicke, T. Greenfield (eds.), *The Provincial Archaeology of the Assyrian Empire*, Cambridge, McDonald Institute for Archaeological Research, 141-150.

Morandi Bonacossi D., Iamoni M. 2015, *Landscape and settlement in the Eastern Upper Iraqi Tigris and Navkur Plains (Northern Kurdistan Region, Iraq). The land of Nineveh archaeological project, seasons 2012-2013*, «Iraq», 77, 9-39 (https://doi.org/10.1017/irq.2015.5).

Nieuwenhuyse O.P., Wilkinson T.J. 2008, *Late Neolithic settlement in the area of Tell Beydar (NE Syria)*, in M. Lebeau, A. Suleiman (eds.), *Beydar Studies* I, Subartu XXI, Turnhout, Brepols, 267-304.

Pfälzner P., Sconzo P., Beutelscheiss R., Edmonds A., Glissmann B., Herdt S., Herrmann J.T., Heydari-Guran S., Kohler J., Mueller Weiner M., Puljiz I., Sharp M. 2016, *The Eastern Habur archaeological survey in Iraqi Kurdistan. A preliminary report on the 2014 season*, «Zeitschrift Für Orient-Archäologie», 9, 10-69.

Pirowski T., Marciak M., Sobiech M. 2021, *Potentialities and limitations of research on VHRS data: Alexander the Great's military camp at Gaugamela on the Navkur Plain in Kurdish Iraq as a test case*, «Remote Sensing», 13, 5, 904 (https://www.mdpi.com/2072-4292/13/5/904).

Poidebard R.P.A. 1934, *La trace de Rome dans le désert de Syrie. Le limes de Trajan a la conquéte arabe. Recherches aériennes (1925-1932)*, Paris.

Soroush M., Mehrtash A., Khazraee E., Ur J.A. 2020, *Deep learning in archaeological remote sensing: Automated qanat detection in the Kurdistan Region of Iraq*, «Remote Sensing», 12, 3, 500 (https://www.mdpi.com/2072-4292/12/3/500).

Starková L. 2020, *Toward a high-definition remote sensing approach to the study of deserted medieval cities in the Near East*, «Geosciences», 10, 369 (https://doi.org/10.3390/geosciences10090369).

Titolo A. 2021, *Use of time-series NDWI to monitor emerging archaeological sites: Case studies from Iraqi artificial reservoirs*, «Remote Sensing», 13, 4, 786 (https://www.mdpi.com/2072-4292/13/4/786).

Ur J., Babakr N., Palermo R., Creamer P., Soroush M., Ramand S., Nováček K. 2021, *The Erbil Plain Archaeological Survey: Preliminary results, 2012-2020*, «Iraq», 83, 205-243.

Valente R., Maset E., Iamoni M. 2022, *Archaeological site identification from open access multispectral imagery: Cloud computing applications in Northern Kurdistan (Iraq)*, «Archaeological Prospection», 29, 4, 1-17 (https://doi.org/10.1002/arp.1874).

Ward Jr. J.H. 1963, *Hierarchical grouping to optimize an objective function*, «Journal of the American Statistical Association», 58, 301, 236-244.

Wilkinson T. 2003, *Archaeological Landscapes of the Near East*, Tucson, University of Arizona.

Wilkinson T.J., Ur J.A., Hritz C. 2013, *Settlement archaeology of Mesopotamia*, in T.J. Wilkinson, G. McGuire, M. Widell, *Models of Mesopotamian Landscapes. How Small-Scale Processes Contributed to the Growth of Early Civilizations*, BAR International Series 2552, Oxford, Archaeopress, 34-55.

Wirth E. 1962, *Agrargeographie des Irak*, Hamburg.

ABSTRACT

The paper presents the results of a two-year archaeological survey carried out in the Iraqi Kurdistan, namely within the Navkur plain that has been extensively explored by the University of Udine since 2012. The surveys were planned in advance using Remote Sensing products available online and processed with Google Earth Engine, a large-scale cloud computing service specifically designed to process geospatial big data and especially satellite imagery. Images from Landsat 5, Landsat 7 and Sentinel-2 platforms were selected, processed and assessed. After two years, an overall number of 46 new and previously unknown sites have been localized and surveyed, contributing to the knowledge of the past history of this portion of the Kurdistan region and testing the use of Remote Sensing cloud-computing applications in the context of Near Eastern archaeological research.

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LEGACY IMAGERY, CONTINUOUS SATELLITE MONITORING AND TARGETED DRONE SURVEYS FOR THE STUDY OF DESERTED MEDIEVAL FORTIFIED SETTLEMENTS IN THE HINTERLAND OF RAVENNA, ITALY

1. Introduction

A general phenomenon of nucleation of the rural population has been recorded in many regions of Western Europe during the Middle Ages, especially between the 8th and 13th centuries (Hamerow 2002, 121-124; Curtis 2013). However, many of these settlements have undergone a contemporary selection process, resulting in many becoming 'deserted' (Curtis 2014). The 'deserted medieval villages' historiographical theme developed significantly in the 1950s and 1960s, thanks to the interest generated across several disciplines, including history, geography, and historical demography (Rao 2011). Soon after, Italian medieval archaeology developed a strong interest in abandoned rural settlements, especially between the second half of the 1960s and early 1970s (Augenti 2016, 16-26). At first, this experience remained essentially limited to a few regions, namely Liguria, Tuscany, Sicily and Sardinia (Galetti 2012, 205), while for Emilia-Romagna and more generally for the Po Valley, a genuine interest in abandoned villages developed only in the 1980s with the work of Aldo Settia (1984). After him, the phenomenon of deserted villages in the Po Valley remained strictly connected to castles, namely sites with elements of fortification and the 'decastellamento process' causing their abandonment (e.g. Saggioro 2011; Gelichi, Librenti, Marchesini 2014).

Even with the increasing archaeological knowledge acquired in the area over the last two decades, most of the abandoned villages in the Po Valley that we know of are still classifiable as castles for their fortified nature. These are, in fact, often characterised by the presence of a motte surrounded by a combination of defensive elements like embankments, ditches, palisades and/or walls (Augenti 2016, 159). Many more examples of these types of fortified settlements have been discovered in various areas of the Po Valley, primarily through aerial archaeology (Wilson 2000; Rączkowski 2014), which has exponentially increased our ability to map and understand this site typology. Identifying anomalies in vegetation growth (= crop marks) or simply in the colour of the exposed bare soil (= soil marks) can allow us to quickly recognise prominent features like mottes and moats. At the same time, while LiDAR data helped reveal deserted medieval settlements in hilly and mountainous areas, like in the Basilicata region in Southern Italy (Masini *et al.* 2018; Masini, Lasaponara 2021), they are not always valuable for flat areas with widespread mechanised farming, which may have led to the destruction of any original micro-relief. A recent and well-documented example is the levelling of the motte of Trifolce in Castel Guelfo (BO) that occurred only in 2003 (Librenti, Michelini, Molinari 2004, 29-30).

Despite some possible limitations, remote sensing helped us partially overcome one of the significant difficulties in locating early and high medieval sites, namely the diffuse use of perishable construction materials that hinder their general visibility (Settia, Marasco, Saggioro 2013), allowing us to map many deserted settlements across the Po Valley. Up to now, most of the known sites are located in the provinces of Verona (Saggioro 2010; Saggioro, Varanini 2013), Treviso (Grandi, Laudato, Masier 2013), Reggio Emilia (Mancassola 2006), Modena (Gelichi, Librenti 2008; Librenti 2018), and Bologna (Librenti, Michelini, Molinari 2004; Grandi 2010; Gelichi, Librenti, Marchesini 2014, 407-408; Librenti 2019).

The provinces of Romagna, a historical region that now constitutes the SE part of Emilia-Romagna, are missing from this list. Since a few decades ago, the lack of deserted medieval villages could have been explained by 20th century historiography that considered this region exceptional in the Italian peninsula due to a stronger Byzantine heritage. According to this assumption, this Byzantine tradition had supposedly prevented the development of the manor system based on *curtes* and the subsequent incastellamento (for a review, Settia 2018). However, both historical (Mancassola 2008a; Pallotti 2018) and archaeological (Mancassola 2008b; Negrelli 2008) studies have questioned this previous reconstruction in the last two decades, proving that both phenomena also spread in Romagna, albeit with their peculiar characteristics.

In addition, previous studies have successfully listed an impressive number of castles in the Romagna region, trying to locate them through place names and historical cartography and reconstruct both their birth and abandonment (Mancini, Vichi 1959; Montevecchi 1970; Augenti, Ficara, Ravaioli 2012; Ravaioli 2015). However, remote sensing has never been used extensively to map this site typology, despite some fortuitous but exceptional discoveries already hinted at its potential, like the features mapped over the sites of Fusignano Vecchio (Cani, Zaccari 1991) and S. Maria in Castellaccio (Abballe, Cavalazzi 2021), the fortress of Cervia Vecchia (Augenti *et al.* 2020), and several abandoned castles located NW of Imola (Librenti, Michelini, Molinari 2004; Grandi 2010; Librenti 2016).

In an attempt to try to bridge this knowledge gap, a large number of legacy images spanning the last 40 years has been exploited to investigate the whole study area in search of archaeological features, especially over known or hypothetical castles. The number of datasets of aerial (national and regional) and satellite (provided free of charge by private companies)

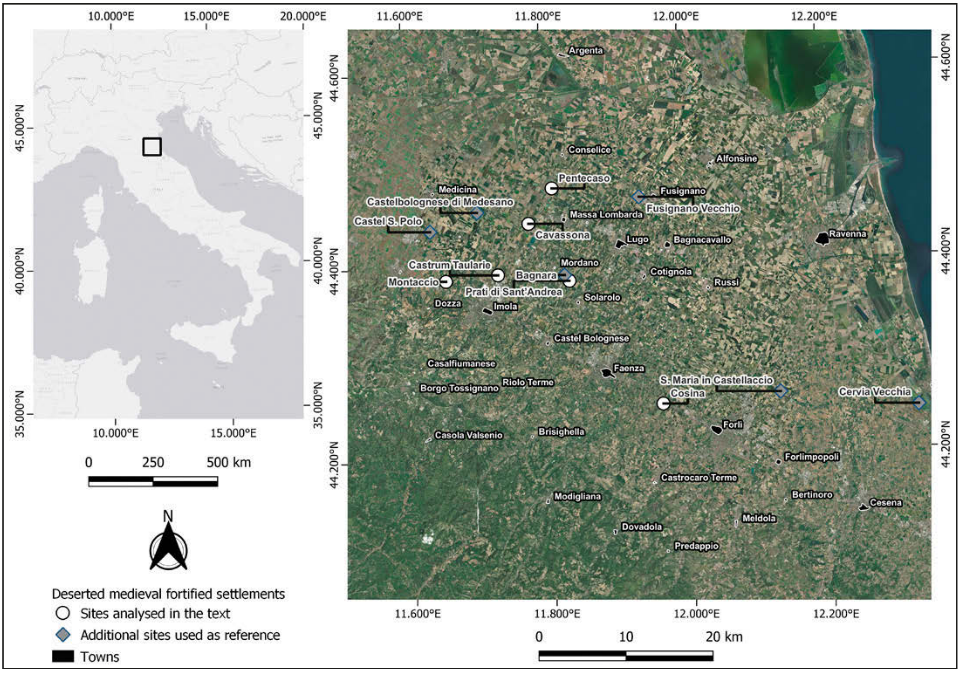

Fig. 1 – Study area with main towns and all deserted medieval fortified sites discussed in the text.

images is constantly increasing, dramatically boosting our chances that an archaeological site had been documented during a favourable period for crop/soil marks formation. For instance, excellent conditions usually present when grasses like wheat or alfalfa grow during summer when less water is available for the plants (Wilson 2000). Moreover, additional high-resolution images can be captured at no cost nowadays, thanks to the spread of commercial drones, targeting acquisition campaigns at the optimal period. However, optimal planning is yet primarily theoretical because it is not always possible in practice to predict the best times for the formation of crop marks, which are caused by complex soil-plant-weather-human interactions acting at a local scale that are not entirely foreseeable.

In response to these historical and methodological shortcomings, this paper firstly discusses the significant contribution that legacy aerial and satellite data can provide to studying deserted fortified settlements, allowing the mapping of defensive elements and reconstructing the general morphology of six medieval sites in the broader hinterland of Ravenna, in Northeast Italy (Fig. 1). Secondly, it presents the results of a combined approach between continuous remote surveillance via PlanetScope multispectral images at 3 m resolution (Planet Team 2017) and subsequent targeted data collection via drone survey to document at higher resolution crop/soil marks barely visible in the satellite data.

2. Materials and methods

The first part of the research involved a systematic inspection of all aerial and satellite images freely available online (Fig. 2), searching for possible crop and soil marks in the study area and specifically on known/hypothetical locations for deserted medieval sites based on published literature. As these legacy images were consulted online or on QGIS as basemaps, it was impossible to carry out advanced image processing techniques or calculate indices. The approach used to enhance images was to increase the contrast and/or brightness to facilitate the interpretation.

The second phase consisted of targeted remote surveillance over selected sites using almost daily PlanetScope satellite data at 3 m resolution. Images were acquired with a minimum of four bands (eight after August 2021) ranging from 455 to 888 nm, allowing True (RGB) and False Colour (NirRG) visualisations, as well as NDVI computation, to further emphasise possible features. This satellite-based remote surveillance was carried out between 2020-2022, from June to September, which proved to be the most fruitful for the formation of archaeological marks based on the previous analysis of legacy data.

Once possible marks were identified in the PlanetScope images, a targeted drone flight was carried out in the days immediately after to document any features at higher resolution, to confirm what had already been seen in the legacy data and potentially identify new elements. The drone employed in the field was a DJI Mavic Pro 2 with a 20-megapixel Hasselblad optical camera. In the case of Cavassona, a targeted artefact survey was carried out to collect dating materials to interpret this site correctly. The surveyors walked 1 m apart and recorded each find with a Garmin GPSMAP 64S handheld GPS (for more information on survey methodology, Cavalazzi *et al.* 2018; Cavalazzi, Abballe, Ferrari 2022).

3. New data on deserted medieval fortified settlements

3.1 *Pentecaso*

The first site considered corresponds to Pentecaso, an abandoned castle that the local tradition places 4 km southern than Conselice (Fig. 1). The earliest mention of the place-name dates to 1145 CE, when the written sources recall an *ecclesia Sancti Iohannis in Pantagase*. A century later, settlers from Lombardy were granted permission to move into the area in 1262. However,

Source	Year	Type	Sensor
Istituto Geografico Militare Italiano (IGMI) – Volo GAI (Gruppo Aeronautico Italiano)	1954/1955	Aerial	B/W
Ministero dell'Ambiente e della Tutela del Territorio e del Mare (MATTM)	1988/1989 1994/1996 2000 2006/2007 2012	Aerial	B/W (first 2 series) RGB (last 3 series)
Agenzia per le Erogazioni in Agricoltura (AGEA)	2008, 2011	Aerial	RGB NIR
Consorzio telerilevamento agricoltura (TeA)	2014, 2017	Aerial	RGB
Compagnia Generale Riprese Aeree (CGR)	2018, 2020	Aerial	RGB NIR
Google Earth Pro	2003 – 2021	Satellite	RGB
Microsoft Bing	2009 – 2020	Satellite	RGB
Esri World Imagery	2011 – 2018	Satellite	RGB

Fig. 2 – Analysed historical and legacy images with provider, temporal coverage, type of systems and sensors.

a fortification attempt is recalled only around the end of the 13th century, promoted by the Communes of Imola and Faenza. After this mention, the site of Pentecaso apparently disappeared from the written sources (Pancino 1995, 63-65).

The legacy data revealed an impressive number of crop marks only on 8th August 2017 (Fig. 3a): an articulated crevasse splay coming southbound from a palaeochannel of the Santerno river, probably deactivated around the 13th century CE (i.e. *paleodosso di S. Patrizio*, Franceschelli, Marabini 2007, 33); a regular subdivision of the field through rectangular plots of around 170×100 m interpretable as paddies mapped by the Catasto Austriaco (1853) when rice cultivation was widespread in the area (Pancino 1995, 162-168); a 65×65 m square, 10 m wide, characterised by a lighter colour, delimiting an inner part measuring around 0.2 hectares, interpretable as an embankment now levelled where compacted soil hinders vegetation growth. If the presence of an apparent embankment seems to confirm the fortified nature of Pentecaso, its limited dimensions make it difficult to imagine a large population living within the fortifications, which was probably meant to protect more significant elements like the church or a possible local authority headquarter and/or provide shelter to the rural population only when necessary.

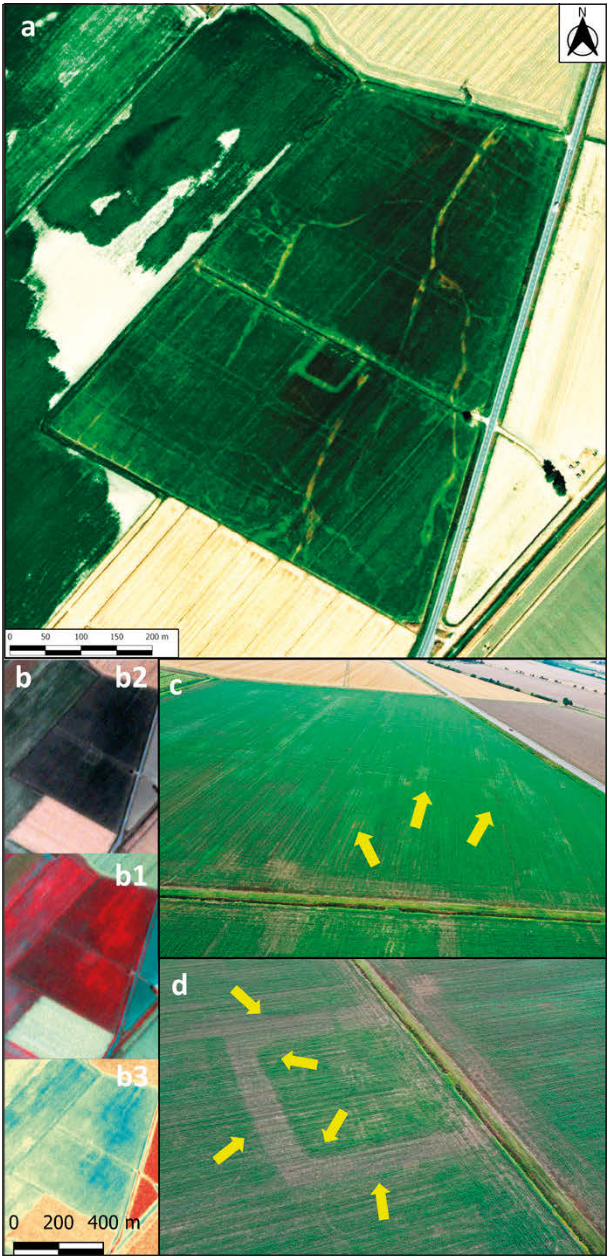

Fig. 3 – Site of S. Giovanni in Pentecaso with anthropogenic elements highlighted by arrows: a) WV03 satellite image captured on 8th August 2017 provided by ESRI; b) PlanetScope image of 24th July 2021 in RGB (b1), False Colour (b2) and NDVI (b3) visualisations; c-d) drone images of 27th July 2021.

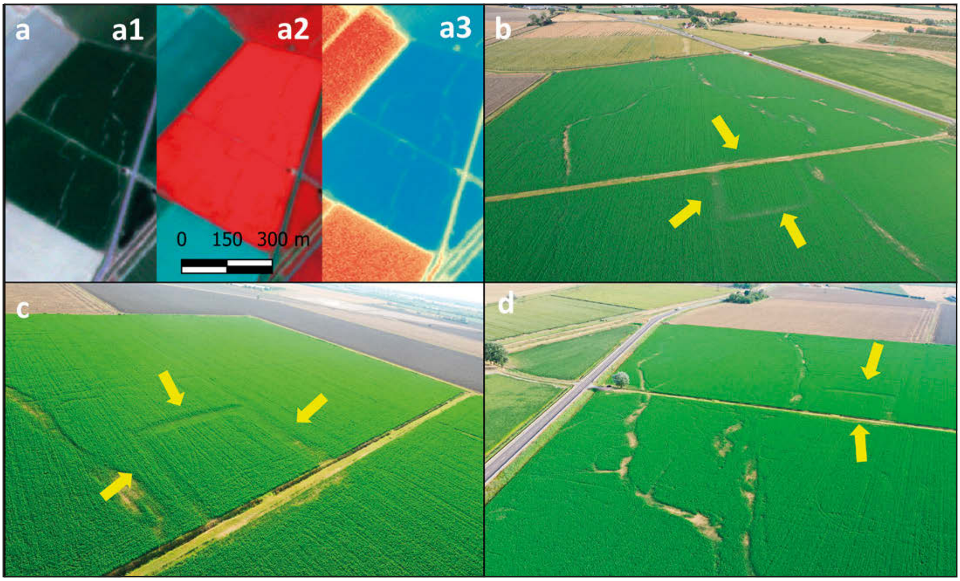

Fig. 4 – Site of S. Giovanni in Pentecaso with anthropogenic elements highlighted by arrows: a) PlanetScope image of 6th August 2022 in RGB (a1), False Colour (a2) and NDVI (a3) visualisations; b-d) drone images of 8th August 2022.

Considering the results of the combined remote-field analysis, the large square feature was recognised on PlanetScope images of 24th July 2021 (Fig. 3b), while the subsequent drone shots also documented the rice paddies remains (Fig. 3c-d). A year later, both square feature and crevasse splay were recognisable on PlanetScope images of 6th August 2022 (Fig. 4a), whose presence was confirmed by the drone survey together with the rice paddies partitioning elements (Fig. 4a-c).

3.2 *Cavassona*

The second site analysed is called Cavassona, after the 19th century toponym attested by IGM Primo Impianto in the area, located in the municipality of Imola (Fig. 1). Several crop and soil marks had already been recognised through Google satellite images (Chouquer 2015, 134-135), suggesting the presence of a rectangular feature measuring around 85×50 m, bordered at least on the N side by a possible defensive embankment circa 8 m wide, now levelled. This embankment may have had one ditch on each side, making the whole defensive structure circa 18 m wide, possibly connected by a small canal to a larger palaeochannel for water intake (Abballe, Cavalazzi 2021).

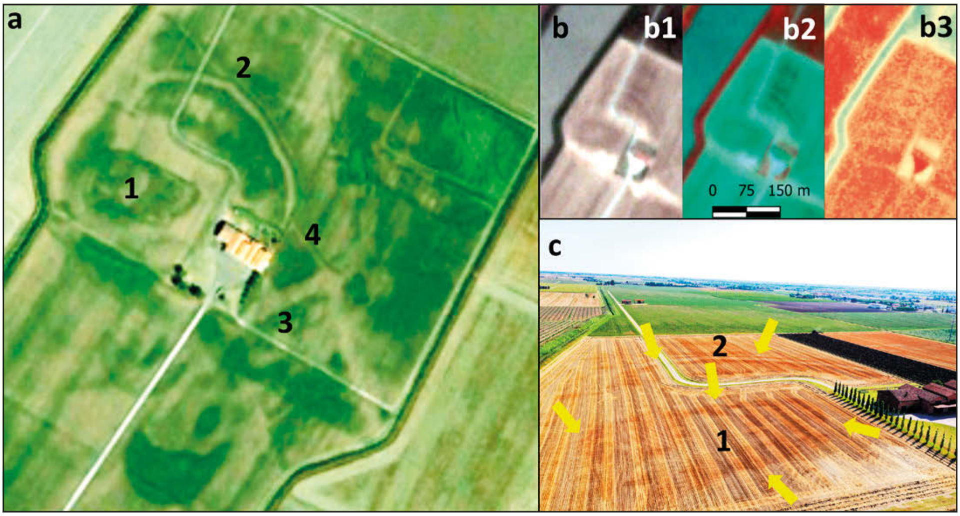

Fig. 5 – Site of Cavassona: a) Google Earth image of 23rd September 2003 with motte (1), defensive system (2), natural palaeochannel (3) and smaller anthropogenic one (4), connecting the former watercourse with the moats of Cavassona (modified from Chouquer 2015, 134-135); b) PlanetScope image of 10th July 2020 in RGB (b1), False Colour (b2) and NDVI (b3) visualisations; c) drone image of 14th July 2020 with levelled motte (1) and fortified system (2) visible as soil marks and highlighted by arrows.

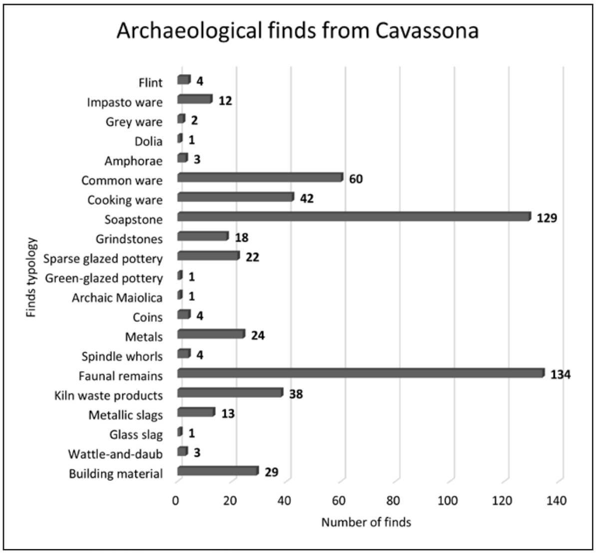

Fig. 6 – Column chart with the finds collected during the survey of Cavassona moated site in 2020.

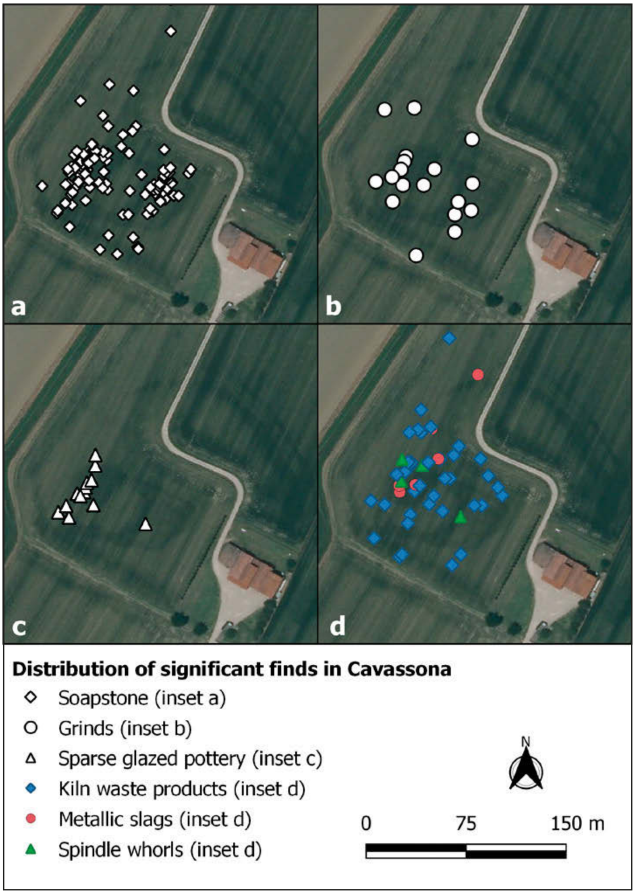

Fig. 7 – Distribution of significant finds: a) fragments of soapstone vessels and b) grindstones imported from the Alpes; c) sparse glazed pottery sherds; d) indicators of productive activities (MATTM 2012 imagery as base map).

The remote surveillance allowed the identification of the defensive system and central rectangular feature as soil marks on 10th July 2020 (Fig. 5b), not visible in the NDVI visualisation (Fig. 3b). On 14th July 2020, a first drone survey was carried out to confirm the presence of the soil marks over the stubble field (Fig. 5c) and to plan a systematic artefact survey to collect dating material to overcome the lack of previous historical and archaeological data on this site. More than 600 finds were collected, mostly dated to the Early/High Middle Ages (Fig. 6), although there were also some Bronze and Iron Ages finds (Abballe, Cavalazzi 2021).

These finds (Fig. 6), mainly clustered near the feature interpretable as a levelled mound (Fig. 7), suggest the presence of a settlement very well connected to the trade networks of the time, considering the impressive number of fragments of soapstone vessels (Fig. 7a) and grindstones in garnet chlorite schist (Fig. 7b) of alpine provenance, and a significant quantity of sparse glazed pottery (or 'vetrina sparsa') sherds (Fig. 7c). Local production activities are attested by spindle whorls for weaving (three out of four are glazed), slags and kiln waste products (Fig. 7d). Among the oldest finds we can count a 9th/10th centuries cooking sherd 'tipo Piadena' (Mancassola 2005), while three Lucchese coins suggest occupation during the 11th/12th centuries (Moretti, Cantatore 2021), disrupted within the 13th century as indicated by the minimal number of Maiolica and Green-glazed wares.

The *castrum de la Fracta*, *castrum Aquevive*, and *castrum Bolegnano* known in the sources but whose location is doubtful (Montevecchi 1970), could all be identifiable with site of Cavassona, but a precise attribution is not yet possible. However, we have a better understanding of the geomorphological transformations that occurred around the 13th century near Cavassona, where several river breaches led to a substantial rise of the otherwise flood-prone landscape. The area was soon after organised through a regular field system around the newly founded centre of Massa Lombarda (Abballe 2022).

3.3 *Castrum Taularie*

The third site is *castrum Taularie* (Fig. 1), attested four times between 1126/1130 and 1215 CE, until the place name ceased to be associated with a fortification changing to *curte Taularia* in 1226 and then *Villa Vidigliani* in the 14th century (Montevecchi 1970). The possible location of *castrum Taularie* was suggested to be near the farmhouse known as Castellaccio around 4 km N of Imola (Montevecchi 1970) and supported by the identification of medieval finds (Librenti 1994, 168, fig. 46). Still, no clear evidence for the site morphology or any defensive elements had ever been identified.

The systematic study of all legacy data allowed us to recognise a clearly visible positive crop mark in Via Bicocca at the hypothetical site of the abandoned castle, identifiable in a Google Earth image of 16th June 2017. This L-shaped feature is at least 160 m long and 8 m wide (Fig. 8a), and it is characterised by a darker colour, due to a healthier vegetation growth than the rest of the field. The shape and characteristics of this crop mark suggest identification as a ditch, which presumably retains more water and helps vegetation growth. The considerable width of this linear feature made it recognisable also in the PlanetScope images when it was clearly evident again as a positive crop mark on both 11th July 2020 (Fig. 8b) and 12th July 2021 (Fig. 8c). During the two subsequent drone flights, it was possible to confirm the

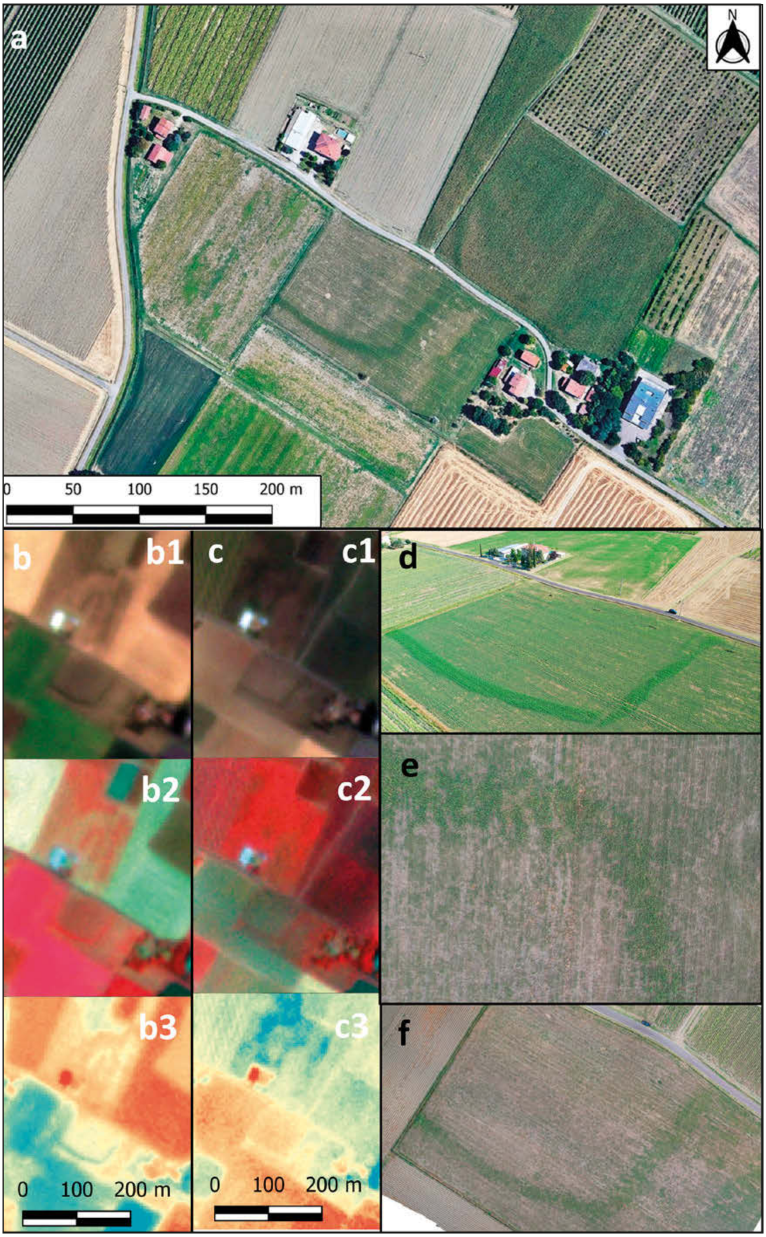

Fig. 8 – Site of *castrum Taularie* with section of moat visible: a) satellite image captured on 16th June 2017 provided by Google Earth Pro; b-c) PlanetScope images of 11th July 2020 and 12th July 2021 in RGB (b1-c1), False Colour (b2-c2) and NDVI (b3-c3) visualisations; d) drone image of 14th July 2020; e-f) drone vertical image and orthophoto of 18th July 2021.

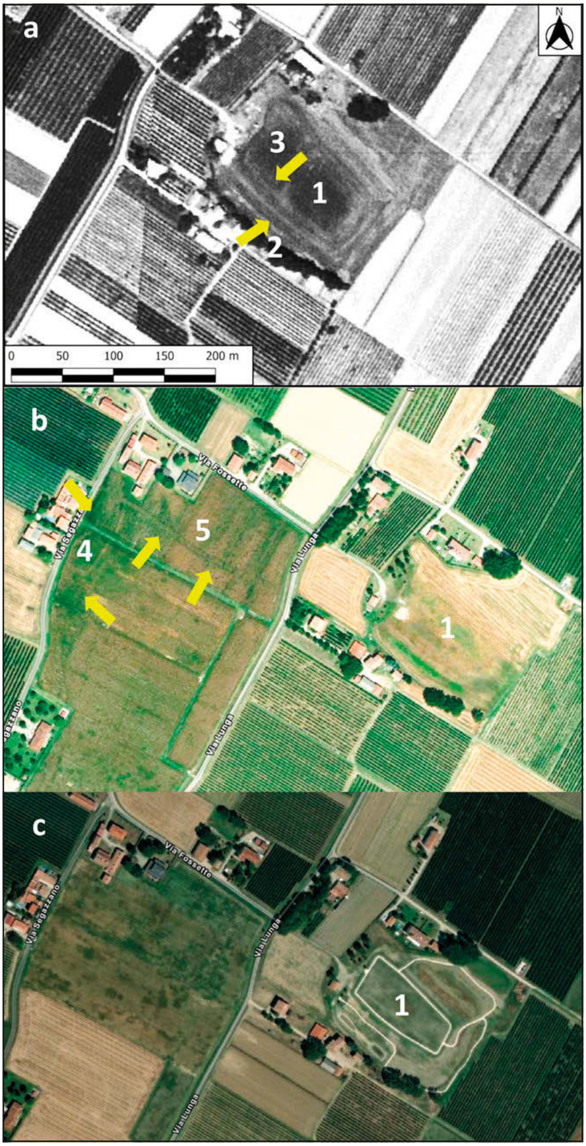

Fig. 9 – Site of Prati di Sant'Andrea/Bagnara Vecchia (1) and main elements highlighted by arrows: a) b/w legacy aerial image provided by Mattm (1996) suggesting the presence of a system with double moat, an external one (2) and a more internal one (3); b) WV03 satellite image captured on 8th July 2017 provided by ESRI with crop marks of a possibly natural palaeochannel along Via Segazzano (4) and a possible anthropogenic one (5), connecting the former watercourse with the moats of Bagnara Vecchia (1); c) WV02 satellite image captured on 29th July 2021 provided by ESRI documenting the site of Bagnara Vecchia (1) after the establishment of a natural restoration area and archaeological site.

presence of the positive crop mark in the alfalfa, healthier and slightly higher in correspondence with the possible negative evidence (Fig. 8d-f).

3.4 *Prati di Sant'Andrea/Bagnara Vecchia*

The fourth investigated deserted medieval site is the motte of Prati di Sant'Andrea, also known as Bagnara Vecchia (Fig. 1), attested in the sources as *curtis* from the 9th century and then as castle *Balnarie* from the 12th century. The site was supposedly destroyed in 1222 by the Communes of Faenza and Bologna (Augenti, Ficara, Ravaioli 2012, 82), with the surviving population probably relocated towards the nearby settlement of Bagnara, the present-day historic centre (Augenti, Ficara, Ravaioli 2012, 79-81). The site has been excavated since 2005 by the local Soprintendenza and has recently been converted into a natural restoration and archaeological area called *Ai prati di Sant'Andrea*.

The presence of a defensive moat was already known, as it was still recognisable in the field. Still, the study of legacy images has enabled new elements of crucial relevance to be mapped. Firstly, a second internal ditch inside the one already known can be seen in an aerial b/w image from the 1990s (Fig. 9a). Both features are characterised by a darker colour compatible with a filled negative feature, albeit only archaeological excavations could assess whether they were functioning simultaneously or if they belong to different chronological phases. Secondly, a possible artificial canal 7 m wide can be seen in a WV02 satellite image captured on 29th July 2021 provided by ESRI (Fig. 9b, n. 5), originating from a much larger palaeochannel (Fig. 9b, n. 4), running parallel to Via Fossette for 200 m and potentially joining the (double) moat system of Bagnara Vecchia (Fig. 9b, n. 1). If what we mapped was indeed the canal supplying water to the medieval moat system, this means the palaeochannel along Via Segazzano was not ultimately filled up at the time (Fig. 9b, n. 4), although it is probably the silting watercourse that in the Bronze Age created a significant fluvial ridge in the area, known as *paleodosso di Bagnara* (Franceschelli, Marabini 2007, 29-30).

The importance of these legacy images becomes even clearer when we consider the recent transformations undergone by the site to create the natural area. This new configuration is visible in the most recent Google Earth and ESRI images (Fig. 9c) and could prevent marks formation in the coming years.

3.5 *Cosina*

The fifth castle is Cosina, attested by the chronicler Tolosano from Faenza between 1199 and 1220 CE (Rossini 1936, 115-117, 130-131). The location of this abandoned site has been suggested near the farmhouse Piazzetta (Fig. 1), where emerging structures had been seen during ploughing

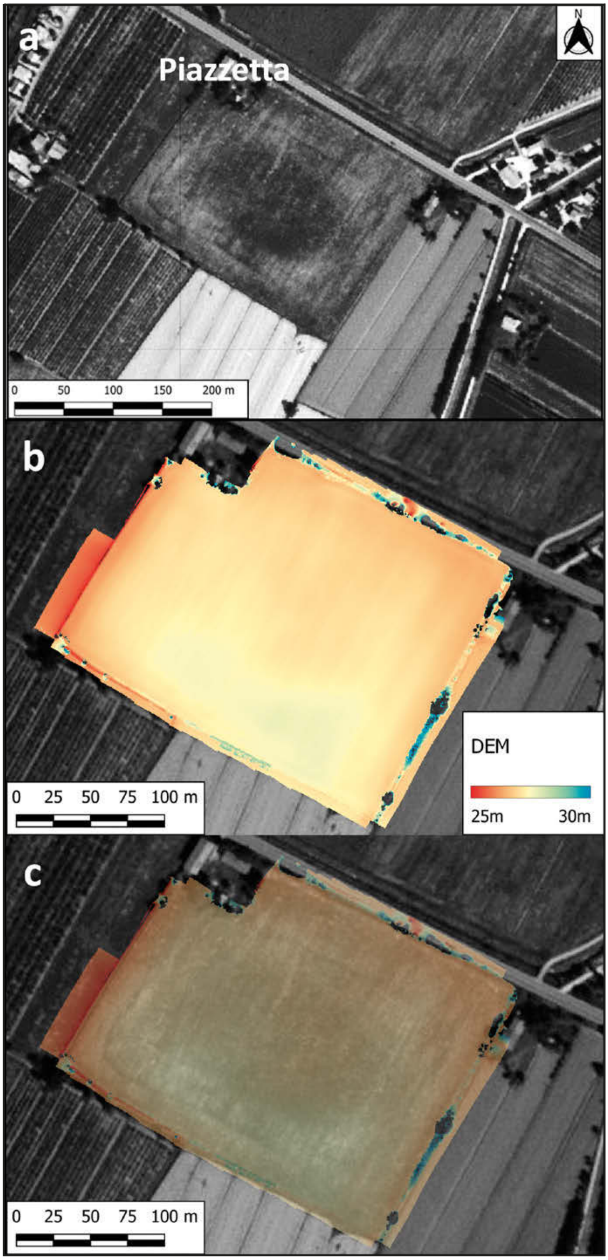

Fig. 10 – Site of Cosina: a) b/w legacy aerial image provided by Mattm (1996) suggesting the presence of a planned site with quadrangular defensive system; b) DEM generated from drone survey on 9th October 2020; c) combined view of DEM and aerial photo.

(Montevecchi 1970, 187), but also further W along Via Carbonara where the toponym *Castellaccium Cosine* is recalled in 1454 and 1524 (Augenti, Ficara, Ravaioli 2012, 147-148). However, an aerial photo from the 1990s allows us to dispel these doubts by showing a rectangular feature of 140×80 m right next to the Piazzetta farmhouse (Fig. 10a). It is characterised by a darker colour, possibly caused by a high organic matter content. Furthermore, a more prominent mark, apparently only a couple of metres wide, seems to enclose the whole site, which measures 200×130 m and occupies a total area of around 2.6 ha. The relatively limited width of this second mark, also characterised by a darker colour, suggests a ditch, which could have had a defensive purpose through the presence of a wooden palisade.

Remote surveillance did not result in the detection of crop marks, which may not have occurred during the three years 2020-2022. Still, a drone photogrammetric survey was carried out to verify the possible presence of a motte in correspondence with the central rectangular feature. As can be seen from the generated DEM (Fig. 10b) and the combined visualisation with the aerial photo (Fig. 10c), no micro-relief of archaeological significance can be currently recognised at the site. If a motte did exist, it was levelled by successive agricultural ploughing, similar to what probably happened at Cavassona (§ 3.2).

3.6 *Montaccio*

The sixth and last site is the *castro quod vocatur Solustra*, mentioned for the first and only time in 1106 CE, whose location has been recognised in the toponym Montaccio, a small mound next to the Sellustra stream at the border between Imola and Dozza (Fig. 1). This hypothesis seems to be confirmed by the finds collected by artefact surveys: soapstone sherds, broadly dated to the Middle Ages (Merlini 1997, 298-305), but also Archaic Maiolica suggesting occupation still after the first half of the 13th century (Librenti 1994, 171).

Although the location of the site seems to be settled, questions remained about its chronology and morphology. A legacy b/w aerial photo from the 1990s (Fig. 11a) allows us to define almost completely the limits of this motte, probably surrounded by a defensive element. Within this large defensive structure, maybe an embankment, there is a smaller feature just a few metres wide characterised by a darker colour, most likely a small ditch, maybe hosting a palisade.

The remote surveillance did highlight some features on 3rd August 2022 (Fig. 11b), especially on the northern edge of the field, visible mainly in the RGB image (Fig. 11b, n. 1) and somewhat less clear in the NDVI visualisation (Fig. 11b, n. 3). However, it was only in the subsequent drone acquisition in the field on 6th August 2022 that a wide range of evidence appeared (Fig. 11c). We can recognise the possible extent of the fortified site in its entirety (Fig. 11c, see arrows), as well as part of the ditch that encircled it that led to

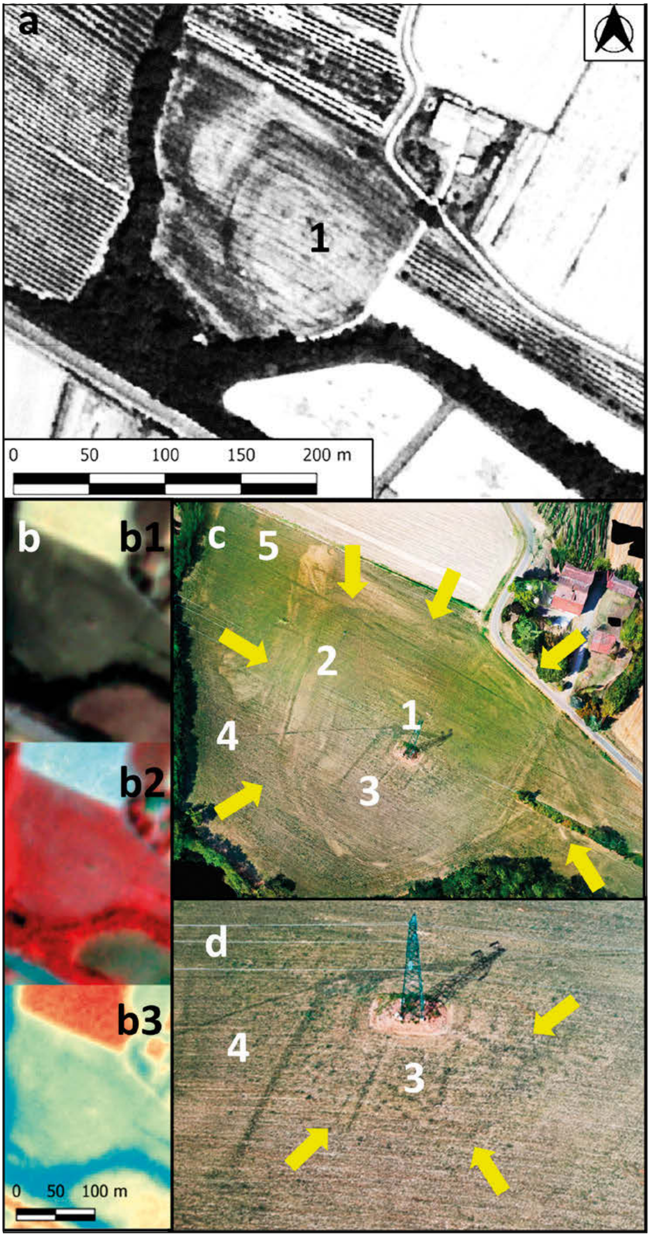

Fig. 11 – Site of Montaccio: a) b/w legacy aerial image provided by MATTM (1996) suggesting the presence of a defensive system; b) PlanetScope image of 3rd August 2022 in RGB (b1), False Colour (b2) and NDVI (b3) visualisations; c-d) drone orthophoto and oblique image of 6th August 2022 with main historical features highlighted by arrows (2-3) and possible modern utilities (4-5).

a distinct positive crop mark (Fig. 11c, n. 2). Also modern traces of underground utilities are visible (Fig. 11c, n. 5), including a gas pipeline laid down in 2011 (Fig. 11c-d, n. 4) as observable in Google Earth images of 30th March 2011. However, some of the linear traces in the centre of the site appear to be archaeological in nature (Fig. 11c-d, n. 3), untouched by the pipeline works, and matching the crop marks documented by Maurizio Molinari through oblique aerial photographs already in the 1990s (Librenti, Michelini, Molinari 2004, 27-28, 43).

4. Discussion

4.1 *The value of legacy images for deserted medieval sites*

The new results discussed demonstrate the potential of the ever-growing number of aerial and satellite image time series collected over the past decades, freely and often easily accessible. These data can help shed light on changes in the landscape (e.g. past river network, Abballe, Cavalazzi 2021), but also on a variety of archaeological sites differing in morphology and chronology, including the deserted medieval fortified settlements discussed in this paper. The systematic study of these remotely sensed data has allowed us to map new defensive elements for six abandoned sites, known mainly by the written sources but whose location was often still hypothetical, making it possible to define their shape and extent in almost their entirety. These data fill a considerable knowledge gap concerning the medieval castles in the hinterland of Ravenna, compared to other neighbouring regions where these sites are much better known, mainly due to the extensive exploitation of remote sensing data (cfr. § 1).

From a historical-archaeological point of view, knowing more about the castles' layouts in this area allows us to make some additional considerations. Rectangular or even square plans are typical for castles of *seconda generazione* (i.e. 12th/13th centuries CE, Augenti 2018), suggesting careful planning like in Cosina and Pentecaso, but also at other nearby sites (Fig. 1), such as Castelbolognese di Medesano, Castel S. Polo (Grandi 2010; Librenti 2019) and Fusignano Vecchio (Cani, Zaccari 1991). Archaeological research found evidence for changes in the pre-existing settlement patterns due to these new foundations in the area northwest of Ravenna (i.e. Bassa Romagna, Cavalazzi *et al*. 2018) and in the near eastern Bologna province (Librenti 2019).

These changes mainly involved further nucleation of the rural population and widespread abandonment of *prima generazione* castles for which a clear preference seems to be recognisable for (sub-)circular fortifications, like in Cavassona. A similar pattern would also be recognisable in Montaccio and *castrum Taularie*, which may have already existed before the beginning of the 12th century when we have the first references to their existence, but not specifically to their birth. Thus, there is a great need for accurate chronological data to better frame these processes, only hinted at here, but it would be essential to repeat the same systematic study in other areas in Italy and Europe where current knowledge on abandoned medieval settlements is lacking, possibly only due to limitations of previous research.

4.2 *Continuous satellite monitoring for planning optimal field surveys*

The paper presents innovative methodological aspects, being among the earliest to evaluate the potential of high temporal frequency PlanetScope satellites for archaeological purposes, specifically in the ability to highlight crop and soil marks indicative of buried features (McGrath *et al.* 2022). The potential of this recently deployed commercial constellation of satellites is significant if compared to the much more employed Sentinel-2, as they offer higher resolution both spatially (3m vs 10m) and temporally (almost daily vs five days revisit time). Moreover, the six cases of deserted medieval fortified settlements discussed above have been used to further test the potential of these 3m satellite images, which allow almost real-time assessment of the land use/land cover over a selected location (with a one-day delay at most between image acquisition and its availability) and nearly every day if no clouds are present on the area.

As mentioned, we monitored six case studies remotely and continuously until possible crop or soil marks could be detected from the PlanetScope data. Once identified, a field verification was carried out via drone flight. The on-site verification documented additional features not visible (or easily interpretable) in the 3m images because of their dimensions, which are smaller than the spatial resolution of the satellite data. For example, the internal partitions of the paddy fields at Pentecaso were not visible in the satellite data (Figs. 3b, 4a), whereas they emerged clearly from the drone photographic documentation (Figs. 3c, 4c-d). Even more surprising are the results from Montaccio, where the satellite data showed very faint differences in vegetation growth (Fig. 11b), while the drone flight mapped both the layout of the site and possible internal structures, as well as modern features (Fig. 11c-d).

These few but significant results demonstrate the potential of this combined approach to target research efforts by only planning field activities when the best state of use (e.g. presence of plants such as wheat or alfalfa) and climatic conditions (e.g. periods of drought) align. Thus, we could overcome a significant limitation of aerial archaeology, which is the apparent randomness in the appearance of archaeological traces that could easily slip out during fieldwork activities. Potentially this approach could also be used on sites with less obvious features, not at all recognisable from satellite data, by estimating the best period for marks formation on the basis of the field land use and regional climatic and moisture data. This strategy could significantly increase the effectiveness of a single drone operator/archaeologist who can often only study a handful of sites per season, allowing the study of more contexts and greatly enhancing the possibility of collecting valuable data.

5. Conclusion

The results presented highlight the high value of legacy aerial and satellite images for identifying and understanding deserted medieval fortified settlements, especially in flat areas where these large sites emerge more easily as crop and soil marks. At the same time, the affordability of drones and the increased temporal coverage provided by satellites such as Sentinel-2 (every five days, provided by the European Space Agency free of charge) and higher-resolution PlanetScope (almost daily, commercial data but often accessible equally free for research purposes), opens the possibility of remotely estimating the best period for new targeted captures, at a higher resolution more significant for archaeological purposes. This approach could also be tested on less prominent sites by combining land use and meteorological data. Moreover, drones equipped with multispectral or thermal cameras could significantly enhance the likelihood of identifying archaeological features across various typological and chronological sites, increasing our knowledge and optimising research efforts.

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REFERENCES

Abballe M. 2022, *Geoarchaeological mapping of medieval wetlands and their reclamation in the hinterland of Ravenna: Two case studies from Massa Lombarda (RA) and Villafranca di Forlì (FC)*, «ArcheoLogica Data», 2, 42-62 (https://www.mappalab.eu/wp-content/uploads/2022/03/03_abballe.pdf).

Abballe M., Cavalazzi M. 2021, *Morphometric analysis for geoarchaeological research: From testing different methods to results verification in the Romagna plain*, «Archeologia e Calcolatori», 32, 1, 117-136 (https://doi.org/10.19282/ac.32.1.2021.07).

Augenti A. 2016, *Archeologia dell'Italia medieval*e, Rome-Bari, Laterza.

Augenti A. 2018, *Castelli, incastellamento e archeologia*, in A. Augenti, P. Galetti (eds.), *L'incastellamento: storia e archeologia. A 40 anni da Les structures di Pierre Toubert*, Spoleto, Fondazione Centro Italiano di Studi sull'Alto Medioevo, 17-37.

Augenti A., Ficara M., Ravaioli E. 2012, *Atlante dei beni archeologici della provincia di Ravenna. Vol. 1: Il paesaggio monumentale nel Medioevo*, Bologna, Ante Quem.

Augenti A., Bondi M., Cavalazzi M., Fiorini A., Sericola M. 2020. *Archeologia dei paesaggi nel territorio ravennate: il progetto Cervia*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 47, 115-139.

Cani N., Zaccari S. 1991, *Fusignano Vecchio. Risultati delle ricerche*, Fusignano, Tipografia Cornacchia & Minguzzi.

Cavalazzi M., Abballe M., Benato A., De Felicibus M. 2018, *Archeologia dei paesaggi in Bassa Romagna. Il Progetto Bassa Romandiola (2009-2016)*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 45, 317-334.

Cavalazzi M., Abballe M., Ferrari A. 2022, *Landscape archaeology in the Ravenna hinterland: The survey at Cotignola (RA), 2018*, «Fasti On Line Documents & Research: Survey», 18 (http://www.fastionline.org/docs/FOLDER-sur-2022-18.pdf).

Chouquer G. 2015, *Les parcellaires médiévaux en Émilie et en Romagne. Centuriations et trames coaxiales. Morphologie et droit agraires*, Paris, FIEF.

Curtis D.R. 2013, *The emergence of concentrated settlements in Medieval Western Europe: Explanatory frameworks in the historiography*, «Canadian Journal of History», 48, 2, 223-251 (https://doi.org/10.3138/cjh.48.2.223).

Curtis D.R. 2014, *Coping with Crisis: The Resilience and Vulnerability of Pre-Industrial Settlements*, Rural Worlds, London, Routledge.

Franceschelli C., Marabini S. 2007, *Lettura di un territorio sepolto: la pianura lughese in età romana*, Bologna, Ante Quem.

Galetti P. 2012, *Fra archeologia e storia: tipologia di insediamenti scomparsi in area emiliano-romagnola*, in F. Panero, G. Pinto (eds.), *Assetti territoriali e villaggi abbandonati (secoli XII-XIV)*, Cherasco, Centro Internazionale di Studi sugli Insediamenti Medievali, 205-232.

Gelichi S., Librenti M. 2008, *Carpi nell'alto Medioevo. Il contributo dell'archeologia alla storia del popolamento*, in P. Bonacini, A.M. Ori (eds.), *Storia di Carpi. La città e il territorio dalle origini all'affermazione dei Pio*, Modena, Mucchi, 209-230.

Gelichi S., Librenti M., Marchesini M. (eds.) 2014, *Un villaggio nella pianura: ricerche archeologiche in un insediamento medievale del territorio di Sant'Agata Bolognese*, Firenze, All'Insegna del Giglio.

Grandi E. 2010, *Il Bolognese orientale tra primo incastellamento e nuove fondazioni (secc. X-XIII)*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 37, 47-60.

Grandi E., Laudato M., Masier S. 2013, *Fortificazioni in terra e legno nella Marca occidentale: i casi delle motte di Castelminio di Resana e Castello di Godego*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 40, 155-166.

Hamerow H.F. 2002. *Early Medieval Settlements: The Archaeology of Rural Communities in North-West Europe, 400-900*, Medieval History and Archaeology, Oxford, Oxford University Press.

Librenti M. 1994, *Tracce di insediamenti altomedievali nella pianura centuriata*, in *Archeologia del territorio nell'Imolese*, Imola, Grafiche Galeati, 168-172.

Librenti M. 2016, *Territorio e insediamento tardomedievale tra Emilia e Romagna*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 43, 57-77.

Librenti M. 2018, *I castelli in area emiliana: alcune riflessioni*, in S. Campagnari, M. Librenti, F. Foroni (eds.), *In loco ubi dicitur Vicolongo. L'insediamento medievale di Santo Stefano a Novi di Modena*, Novi di Modena, Gruppo Studi Bassa Modenese, 41-44.

Librenti M. 2019, *Settlement dynamics in the rural Bolognese area between the Late Middle Ages and the Modern Era*, in S. Gelichi, L. Olmo-Enciso (eds.), *Mediterranean Landscapes in Post Antiquity: New Frontiers and New Perspectives*, Oxford, Archaeopress, 38-63.

Librenti M., Michelini R., Molinari M. 2004, *Catalogo delle fortificazioni in terra e legno nella pianura bolognese orientale*, in *Fortificazioni altomedievali in terra e legno: ricerche territorio e conservazione 3. Convegno nazionale (Castel San Pietro Terme 2002)*, Roma, Istituto Italiano dei Castelli, 25-47.

Mancassola N. 2005, *Le ceramiche grezze di Piadena*, in S. Gelichi (ed.), *Campagne medievali. Strutture materiali, economia e società nell'insediamento rurale dell'Italia settentrionale (VIII-X secolo)*, Mantova, SAP, 143-171.

Mancassola N. 2006, *Interpretazione del dato di superficie altomedievale in area padana. Il territorio a Sud di Ravenna e a Nord di Reggio Emilia*, in N. Mancassola, F. Saggioro (eds.), *Medioevo, paesaggi e metodi*, Mantova, SAP, 115-146.

Mancassola N. 2008a, *L'azienda curtense tra Langobardia e Romania: rapporti di lavoro e patti colonici dall'età carolingia al Mille*, Bologna, CLUEB.

Mancassola N. 2008b, *Le forme del popolamento rurale nel territorio Decimano dalla caduta dell'Impero Romano all'anno Mille*, in M. Ficara, V. Manzelli (eds.), *Orme nei campi. Archeologia a sud di Ravenna*, Firenze, All'Insegna del Giglio, 89-104.

Mancini W., Vichi F. 1959, *Castelli rocche e torri di Romagna*, Bologna, ALFA.

Masini N., Gizzi F.T., Biscione M., Fundone V., Sedile M., Sileo M., Pecci A., Lacovara B., Lasaponara R. 2018, *Medieval archaeology under the canopy with LiDAR. The (re)discovery of a medieval fortified settlement in Southern Italy,* «Remote Sensing», 10, 1598 (https://doi.org/10.3390/rs10101598).

Masini N., Lasaponara R. 2021, *On the reuse of multiscale LiDAR data to investigate the resilience in the late medieval time: The case study of Basilicata in South of Italy*, «Journal of Archaeological Method and Theory», 28, 1172-1199 (https://doi.org/10.1007/s10816-020-09495-2).

McGrath C.N., Cowley D.C., Hood S., Clarke S., Macdonald M. 2022, *An assessment of high temporal frequency satellite data for historic environment applications. A case study from Scotland*, «Archaeological Prospection», 1-16 (https://doi.org/10.1002/arp.1890).

Merlini F. 1997, *La circoscrizione plebana di S. Maria in Sellustra ed il territorio nord-occidentale della diocesi imolese tra l'VIII e il XIII secolo*, in *La pastorale sacramentale in Emilia Romagna nei secoli XVI-XX: Atti del Convegno (Imola 1991)*, Cesena, Badia di Santa Maria del Monte, 291-305.

Montevecchi F. 1970, *Repertorio dei castelli, rocche e torri*, in P. Gazzola, G.F. Fontana, D. Berardi (eds.), *Rocche e castelli di Romagna*, 1, Bologna, Edizioni Alfa, 139-400.

Moretti D.L., Cantatore M.F.A. 2021, *La circolazione del denaro lucchese tra Appennino tosco-emiliano e Po: secoli XI-XII. Un primo bilancio sulla base di fonti scritte e materiali*, in M. Sozzi (ed.), *Aspetti di storia della Toscana attraverso monete e medaglie*, Bari, Edizioni D'Andrea, 39-59.

Negrelli C. 2008, *Dalla tarda Antichità all'alto Medioevo (V-IX secolo)*, in S. Gelichi, C. Negrelli (eds.), *A misura d'uomo. Archeologia del territorio cesenate e valutazione dei depositi*, Firenze, All'Insegna del Giglio, 237-256.

Pallotti R. 2018, *Castelli e poteri signorili nella Romagna settentrionale (secoli XI-XIII)*, Cesena, Società editrice 'Il Ponte vecchio'.

Pancino C. 1995, *Conselice di Romagna. L'infelice situazione*, Ravenna, Longo.

Planet Team 2017, *Planet Application Program Interface: In Space for Life on Earth*, San Francisco, CA (https://api.planet.com).

Rączkowski W. 2014, *Aerial Archaeology,* in C. Smith (ed.), *Encyclopedia of Global Archaeology*, New York, Springer, Cham, 33-38 (https://doi.org/10.1007/978-1-4419-0465-2_1504).

Rao R. 2011, *Nuovi borghi, villaggi abbandonati e genesi del paesaggio: selezione insediativa e processi di diserzione nel Vercellese bassomedievale*, in R. Comba, R. Rao (eds.), *Villaggi scomparsi e borghi nuovi nel Piemonte medievale*, Cuneo, Società per gli Studi storici archeologici ed artistici della provincia di Cuneo, 21-38.

Ravaioli E. 2015, *L'insediamento fortificato in Romagna tra fonti scritte e dati archeologici (VIII-XVI sec.): le province di Forlì-Cesena e Ravenna*, Bologna, Bononia University Press.

Rossini G. (ed.) 1936, *Magistri Tolosani Chronicon Faventinum (aa. 20 a.C.-1236)*, Rerum Italicarum Scriptores, 28, 1, Bologna, Zanichelli.

Saggioro F. 2010, *Paesaggi di pianura: trasformazioni del popolamento tra età romana e Medioevo. Insediamenti, società e ambiente nella pianura tra Mantova e Verona*, Firenze, All'Insegna del Giglio.

Saggioro F. (ed.) 2011, *Nogara: archeologia e storia di un villaggio medievale (scavi 2003-2008)*, Roma, Giorgio Bretschneider.

Saggioro F., Varanini G.M. 2013, *Motte, recinti e siti con fossato nel territorio veronese: dati e riflessioni tra fonti scritte e archeologiche (IX-XIV secolo)*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 40, 133-144.

Settia A.A. 1984, *Castelli e villaggi nell'Italia padana. Popolamento, potere e sicurezza fra IX e XIII secolo*, Napoli, Liguori.

Settia A.A. 2018. *Castelli, incastellamento e fonti scritte*, in A. Augenti, P. Galetti (eds.), *L'incastellamento: storia e archeologia. A 40 anni da Les structures di Pierre Toubert*, Spoleto, Fondazione Centro Italiano di Studi sull'Alto Medioevo, 3-16.

Settia A.A., Marasco L., Saggioro F. (eds.) 2013, *Fortificazioni di terra in Italia. Motte, tumuli, tumbe, recinti. Atti del Convegno (Scarlino 2011)*, «Archeologia Medievale. Cultura materiale, insediamenti, territorio», 40, 7-187.

Wilson D.R. 2000, *Air Photo Interpretation for Archaeologists*, Stroud, Tempus.

ABSTRACT

The nucleation of the rural population was a widespread phenomenon during the Middle Ages that interested many areas of Western Europe. However, many of these sites are now deserted with the underlying phenomena causing these abandonments not always easy to reconstruct. Archaeologists have been interested in these medieval settlements since the middle of the 19th century, and remote sensing has played a decisive role in mapping hundreds of them. This also applies to many parts of the Po Valley but not the Romagna plain, where hundreds of medieval sites are known but almost exclusively based on written sources. However, the increasing availability of aerial and satellite images offers a valuable opportunity to bridge this knowledge gap. The systematic study of legacy images allowed the mapping of new defensive elements and reconstruction of the general plan of six deserted medieval fortified settlements in the broader hinterland of Ravenna. PlanetScope 3m resolution images were later exploited to continuously monitor these sites during periods prone to crop marks formation to detect the presence of wide crop/soil marks (e.g. ditches). Six successful field verifications demonstrate that these 'coarse' images are sufficient to plan drone surveys that can allow the mapping of additional smaller features.

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THE DOMUS OF THE CALENDAR: A QUALITATIVE COMPARISON ANALYSIS OF DIGITAL DATA OBTAINED FROM 3D LASER SCANNERS, SFM METHODOLOGIES, AND PORTABLE DEVICES

1. Introduction

During the last decades, digital survey technologies have been developed at a high rate. This has allowed the production of new instruments and assets to acquire high quality 3D digital geometric and radiometric data of high quality. One of the most interesting improvements of these developments is the possibility of creating realistic and interactive virtual models that accurately reflect physical objects and the dynamics of a physical system (digital twins). The ability to control an accurate replica of the continuum of three-dimensional space (with accurate geometric and chromatic data) expanded the knowledge of Cultural Heritage (Dellepiane *et al.* 2013). This innovative data acquisition paradigm was well received in architecture and archaeology for surveys elaboration, due to its ability to provide reliable graphic support for different types of research, opening new perspectives and opportunities (Ferdani *et al.* 2022). The new digital survey methodologies started to substitute traditional data acquisition instruments (such as direct surveys) because of their versatility and capacity to register extremely accurate data.

Additionally, digital data acquisition instruments allow fast acquisition data-loads and postpone data selection for the restitution phase. This kind of flexibility consents to the application of the acquired data for different purposes that can change over time (Bianchini *et al.* 2016). Nowadays, the most widespread instruments for collecting three-dimensional high-resolution digital data on Cultural Heritage are range-based instruments (such as laser scanners) and image-based instruments (such as high-resolution digital photogrammetry integrated with automatic image elaborations) (Remondino *et al.* 2008, 2014; Remondino 2011). Recent developments in range-based instruments have brought low-cost, and faster data acquisition technologies; for instance, the latest hardware by Apple uses LiDAR and TrueDepth cameras for 3D scanning. Fiorini 2022 provides a review of this technology and an evaluation of its capabilities applied in different architectural and archaeological contexts; Vogt *et al.* 2021 on their part, provides an analysis of its limitations.

In this wide range of possibilities, choosing the most suitable methodology and technology represents a fundamental aspect of determining the qualitative level of the survey. A comprehensive evaluation must consider

Fig. 1 – The Basilica of Santa Maria Maggiore (photo Juan Camilo Arias Tapiero).

different factors, such as the geometrical and physical characteristics of the research object (minimal dimension of detail, bulk, and volume, presence of translucent, mirroring, or darker surfaces, uniform superficial finishing), survey condition (accessibility of the case study), the goals of the restitutions, and the survey instrument's characteristics (accuracy and margin of error, geometric and radiometric resolution, frame field and work distance, etc.).

In Cultural Heritage, because of the wide range of case studies with peculiar and unlikely recurrent characteristics, it is possible to determine an optimized procedure adaptable to the characteristics of the subject. Several experiences of digital three-dimensional high-resolution surveys have shown that, depending on the survey objectives and communication scopes, integrating different survey techniques is the best approach for exploiting the potentialities of each instrument (Ippolito, Bartolomei 2014; Russo, Manferdini2015; Inglese, Luchetti 2022).

The integrated survey project of the Basilica of Santa Maria Maggiore was conceived under this premise, as part of a more extensive project dedicated to the definition of a system of integrated models, which was also implemented in the Basilicas of Santa Maria in Trastevere and San Pietro, in Rome (Bianchini *et al*. 2022). This system was developed to explore the possibilities of integrating different survey technologies, for the whole purpose of using the potentialities of various instruments. The implementation of this system in the Basilica of Santa Maria Maggiore allowed us to build a global model of the entire complex to propose a new reading of the context analyzed while maintaining the data from the urban to a multi-scalar level of detail. This was also the first time that a survey of the whole basilica complex was done; the main body, the archaeological site, and other features in the underground and the upper levels were systemized as a single element of unique historical value. The model thus obtained was subsequently used as a research tool for different study purposes. The survey takes on special importance as the most recent survey of the basilica complex dates from the 60's.

The present paper introduces the most significant results obtained from the comparison of three different survey instruments: the laser scanner (Leica C10 and FARO Focus), Structure from Motion (SfM), and and the iPad LiDAR camera. The results of the comparison analyses exposed here are the ones carried on the Domus of the Calendar, that is, the archaeological site located underneath the basilica which acts as a structural foundation element of the *domus*-basilica complex. The implemented methodology is not limited to this specific case of study, and it can be replicated wherever it is necessary to evaluate the quality of the data obtained from an integrated survey.

2. The Domus of the Calendar

The archaeological remains of the Domus of the Calendar are situated under the Basilica of Santa Maria Maggiore. The basilica is located on the Esquiline, one of the seven ancient hills of the city of Rome. It is one of the four papal major basilicas and the most important religious building dedicated to the worship of Mary (Steinby 1996). The basilica was included in the UNESCO World Heritage List together with all the Holy See's extraterritorial properties in 1990 (Unesco 2021) (Fig. 2). The history of the basilica dates to Pope Liberius (352-366), who started the construction of a church on the highest point of the Esquiline hill (Steinby 1996). The former basilica, known as the Liberian Basilica, seems to have been demolished during the invasion of Rome by Alarico I in 410 AC (Liverani 2013). It is still not clear if the present basilica was initially erected by Celestine I (422-432) or by Sisto III (432-440) (Liverani 2010), but it was built in the same place where the Basilica Liberiana was located. The new church was consecrated to Mary the Holy Mother of God, a decision highly influenced by the Ephesus council's results.

During medieval times, the basilica suffered many interventions, such as the addition of a series of small churches and the reconstruction of the apse (De Blaauw 2015). During the Renaissance and the Baroque, the basilica went over a series of important additions that configured its present appearance. In this period, some of the most important architects in the history of Rome took part in the construction, such as Michelangelo, Domenico Fontana, Bernini, Ferdinando Fuga, and Carlo Rainaldi.

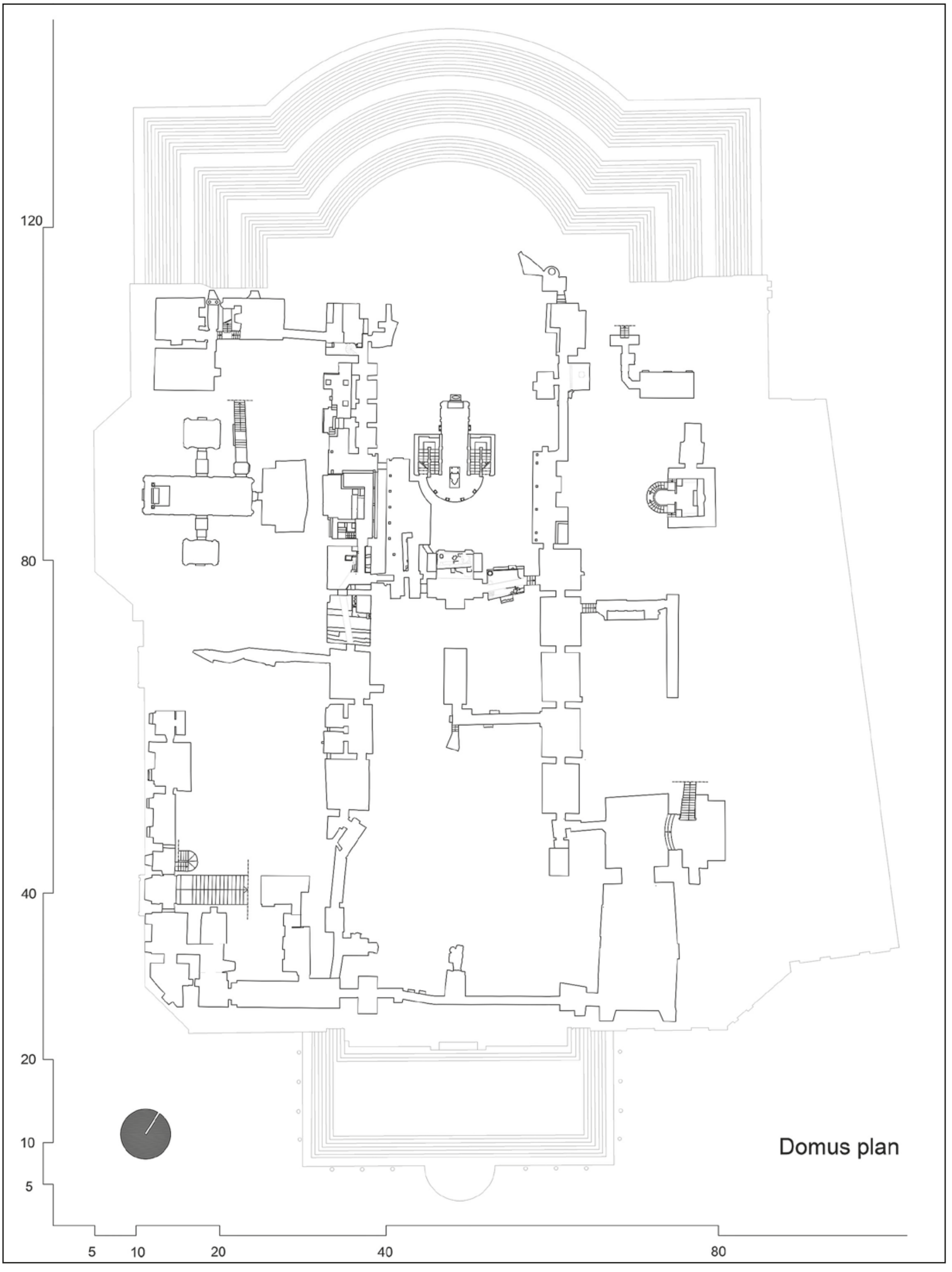

Fig. 2 –The archaeological remains located under the Santa Maria Maggiore Basilica. Plan obtained by laser scanner point cloud.

The archaeological remains located under the Santa Maria Maggiore Basilica were found in 1966 during a series of works aimed at isolating the basilica's ground floor from the soil moisture (Magi 1972). Through this process, the excavations revealed the existence of a Roman building. The most particular findings were the discovery of an exedra, as well as many frescos and mosaics. Among the frescos, it is interesting to note the discovery of a calendar painted on a wall of the Roman building, used as a foundation for the basilica. F. Magi identified the archaeological remains with the *Macellum Liviae*, a shopping complex built by Augustus in the name of his wife Livia. Later studies have contradicted this affirmation and instead have stated that the remains are part of a *domus romana* that belonged to an important noble family. F. Guidobaldi (Steinby 1995) attributed the house to the *gens Nerati*, a powerful and recognized aristocratic family that participated actively in the political and economic life of the city from the centuries 1st AD to the 4th AD (Iannantuono 2010).

G. De Spirito (Steinby 1996) attributes the *domus* to *Flavius Anicius Auchenius Bassus*, a high official and consul of Rome from 425 to 435 AD. Liverani dates the remains to the Claudian or Neronian times (1st century AC) and argues that it is not possible to track the owner of the *domus* as the available information is not specific enough (Liverani 1987). Therefore, he clarifies that the Santa Maria Maggiore Basilica was built over the remains of two Roman houses. Of one of these houses there are very few archeological elements to evaluate its context; the second one, the one with the painted calendar, which he called Domus of the Calendar, is the case study chosen for this investigation.

3. Methodology and data acquisition

The integrated survey project of the architectural and archeological complex of the Basilica of Santa Maria Maggiore was carried out using active and passive terrestrial and aerial technologies. A data acquisition survey was performed using a 3D laser scanner integrated with photogrammetric data acquired from Structure from Motion (SfM) processes – photographic camera and drones for this purpose – and data obtained from the iPad LiDAR scanner. The laser scanner works by determining ranges of distances by targeting an object with a laser and measuring the time for the reflected light to return to the receiver. With this tool, the geometric features of the objects are extracted efficiently. The result of a laser scanner is a point cloud which is an array of points with spatial information of a very high accuracy (coordinates), and RGB information of low accuracy (color).

The SfM is a low-cost technique for estimating 3D information from a sequence of 2D images (photos). The results from this technique are point

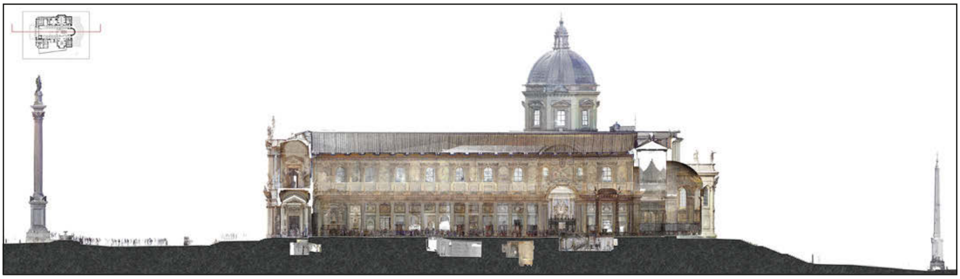

Fig. 3 – Longitudinal section-laser scanner point cloud.

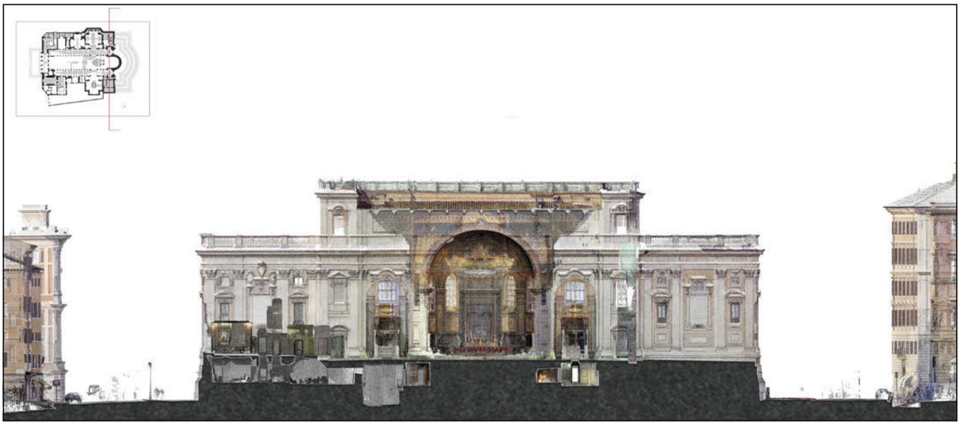

Fig. 4 – Cross section-laser scanner point cloud.

clouds with spatial information of low accuracy and RGB information of high accuracy. However, the accuracy of the spatial information can be increased by adding control points with known coordinates. The SfM also allows to easily generate 3D models with high-quality texture. The iPad LiDAR camera is also a low-cost instrument. It is a relatively new tool that has been adapted for data acquisition by the development of applications; it is also very versatile and allows the user to see in real time the information acquired. This is, perhaps, one of the first times a device of these characteristics is used in a data acquisition survey campaign with archaeological elements. The results of the comparison analysis from this tool can open the way to further investigations due to its innovative nature.

The whole complex was surveyed using a laser scanner. This instrument allows massive data acquisition of large-scale objects with accuracy and speed that would be difficult to achieve using any other instrument; it enables

Fig. 5 – Cross section-laser scanner point cloud.

two-dimensional restitutions with an accuracy of 1 mm on a 1:50 drawing scale. The SfM and the iPad LiDAR scanner were used to complement the laser scanner numerical data by providing higher chromatic information in a level of detail that cannot be achieved with the laser scanner; these technologies were used to survey only selected elements of high aesthetic and historic value. During the surveying campaign, to carry out the qualitative data comparison, four elements from the Domus of the Calendar were chosen. These are archaeological elements of exceptional value. The subjects were surveyed using laser scanners, a photographic camera (Canon EOS RP) and the iPad LiDAR camera (iPad Pro).

To photograph the selected archaeological elements – and given the limited dimensions of the rooms where these are exposed – a 24-105 f/4 mm lens was used, set at a focal length of 24 mm for the entire campaign. The archaeological site is illuminated with strong artificial lights; some of these are directed towards the archaeological remains, generating scenes of notable contrast which does not allow an adequate exposure for a photographic capture. This was addressed by using a controlled lighting system to illuminate only the archaeological elements in the dark. These dim conditions required increasing the exposure time to 10 seconds, so a tripod was necessary to achieve correctly exposed images. The photos were taken in RAW format for highest quality, then post-processed in an image manipulation software and finally exported in TIFF format. The resulting images were processed using the software AgisoftMetashape, which performs photogrammetric operations for the generation of 3D spatial data. Subsequently, filtering the acquired data removes unnecessary elements like the scattered points that do not represent the subject surfaces. The resulting point clouds are scaled to match the spatial data of the laser scanner. The scaling of the point cloud consists in assigning absolute dimensions to the reconstructed elements with relative dimensions.

This phase influences the results of the whole process of reconstruction and comparison; the level of accuracy in its execution unequivocally determines the metric reliability of the final model and the one from relative comparisons between models. By the mean value of three significant lengths selected on the laser scanner model, it was possible to determine the scaling parameter process. This approach is more reliable than comparing single points from the reference model. Decimated data allows effective manageability since the range approach (from the laser scanner) and image-based approach (from the SfM) generate models requiring computational costs that limit the hardware performance when processed. The data was then decimated to allow effective manageability, since in both the range approach (from the laser scanner) and image-based approach (from the SfM) the generated models require computational costs that limit the hardware performance when they are processed. The data obtained from the iPad LiDAR camera was registered using the app SiteScape, a versatile tool for scanning scale-accurate 3D spaces (https://www.sitescape.ai/). This data was not scaled as the LiDAR camera registers accurately the spatial characteristics of the scanned subjects.

For the data comparison, the three-dimensional mathematical models (point clouds) were processed in the software Cloud Compare (http://www.cloudcompare.org/). The SfM models and the iPad LiDAR camera models were aligned with the laser scanner model by using the ICP algorithm (Iterative Closest Point) that helps to minimize errors when aligning the models. This was followed by a spatial deviation comparison in two phases: comparing the laser scanner model with the SfM model and comparing the laser scanner model with the iPad LiDAR camera. This comparison aimed to quantify not only any deviation in terms of distance between the different models; but also other aspects that may affect the three-dimensional reconstruction process, such as costs, skills, time and computational costs, necessary elements to provide an optimized digital model (Figs. 3-5).

4. Results

For the comparison, four representative archaeological elements were selected from the Domus of the Calendar: an exedra (Room IV), a wall with marble incrustations (Room VIII), a mosaic (Room IX) and a portion of the calendar fresco (Room X) (Fig. 6). The results are shown according to the level of complexity of each element, in the following order: 1) mosaic, 2) calendar fresco, 3) wall with marble incrustations, and 4) exedra.The results

Fig. 6 – The photos of four different parts of the four rooms of the the Domus of the Calendar (SfM).

		Points Obtained		
Room	N° Photos (SfM)	Laser scanner	SfM	iPad LIDAR camera
IV (Exedra)	296	10.292.585	93.368.698	878.279
VII (Marble incrustations)	94	1.973.992	2.356.994	437.494
IX (Mosaic)	75	1.268.523	3.536.238	231.374
X (Calendar Fresco)	182	2.704.068	2.992.706	621.209

Tab. 1 – The Point cloud comparison analysis.

are registered in an RGB color scale: blue indicates a minimal variation (0 cm) in comparison to the reference data, green is a medium one (1 cm), while red represents a high one (> 2 cm). The scaled values on Figs. 7, 8, 9, and 10 are represented in meters. The input data for this analysis is shown in Tab. 1.

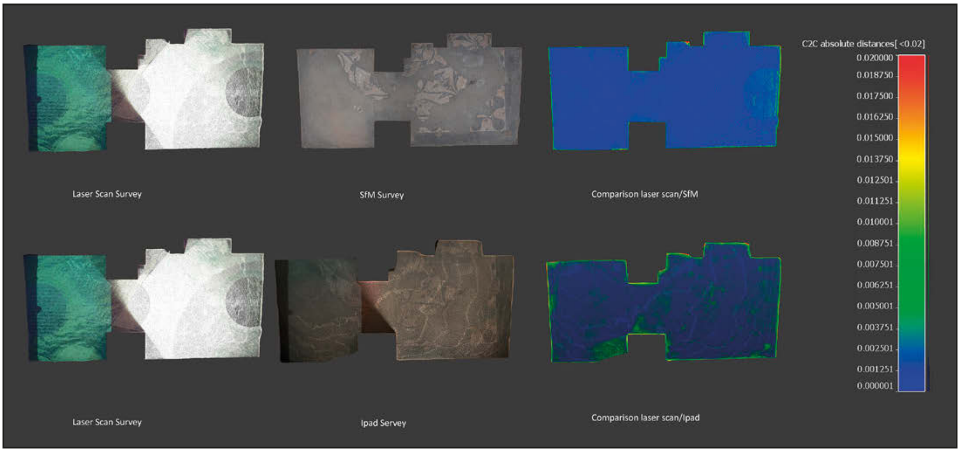

Fig. 7 – The comparison between different survey methodologies (SfM, laser scanner, iPad): Room IX, mosaic.

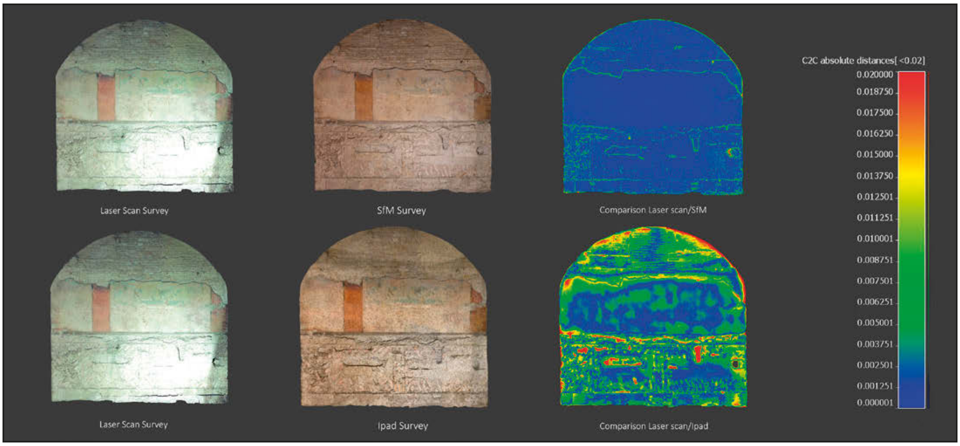

Fig. 8 – The comparison between different survey methodologies (SFM, laser scanner, iPad): Room X, Calendar fresco.

4.1 *Results: laser scanner vs SfM*

The results from this comparison show that the data acquired with the SfM methodology has minimal variations from the data obtained with the laser scanner. Thus, it can represent reality with high accuracy. In the mosaic and the fresco, for example, there is practically no variation between both survey methodologies, as both results appear in blue (Figs. 7, 8). There are

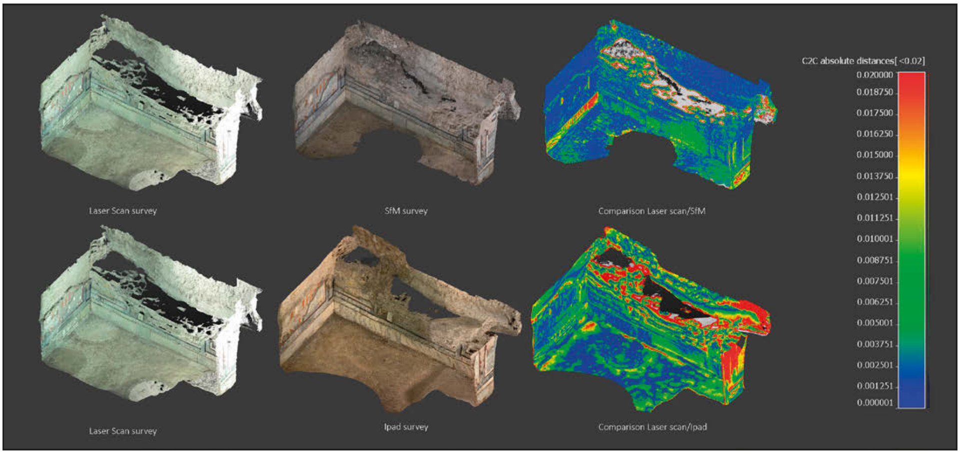

Fig. 9 – The comparison between different survey methodologies (SfM, laser scanner, iPad): Room VIII, marble incrustations.

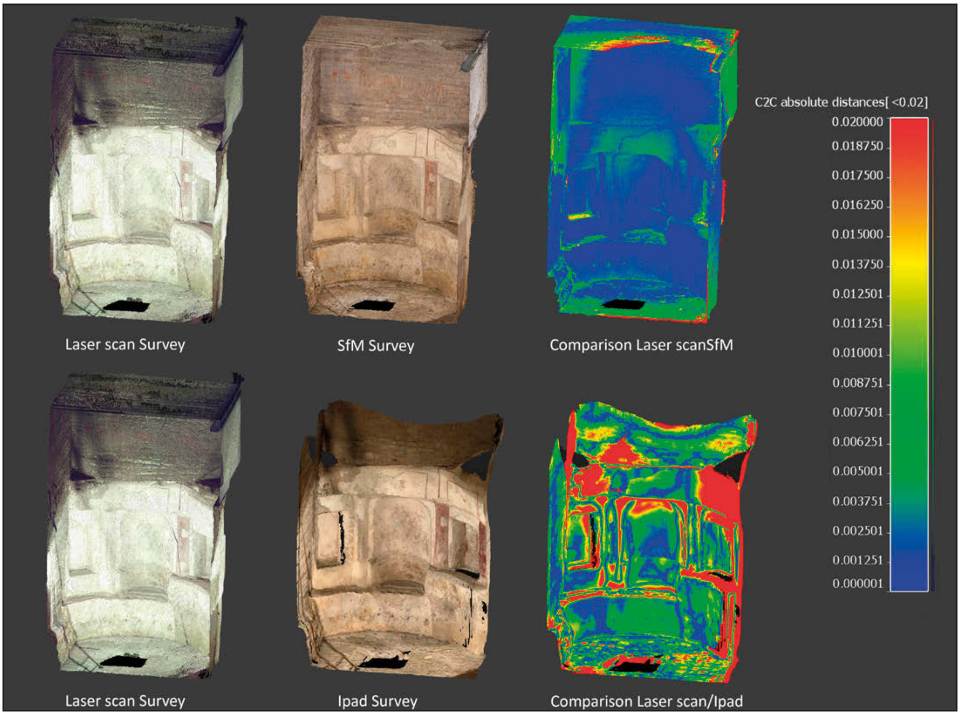

Fig. 10 – The comparison between different survey methodologies (SfM, laser scanner, iPad): Room IV, exedra.

some instances in which the data from the SfM have noises. This noise is registered with a red color on the results from the marble incrustations and the exedra (Figs. 9, 10). This implies that there is a significant variation compared to the reference data. Significant data variations are also present in irregular surfaces. This can be seen in the results in green from the comparison of the wall with marble incrustations (Fig. 9). Elements with complex geometry seem to be well represented by the SfM, especially if the surfaces of the element are regular. This evidence is shown in the results from the exedra, where almost all the information is coloured in blue (Fig. 10).

4.2 *Results: laser scanner vs iPad LiDAR camera*

The results from the iPad LiDAR camera have shown significant variations compared to the laser scanner data. Firstly, it represents good elements with simple geometry, as can be seen from the results of the mosaic with a predominance of the blue color (Fig. 7). When there are minimal protrusions on the surface of the elements, the results vary considerably from the ones obtained with a laser scanner. To be seen comparing the wall fresco of the calendar (Fig. 8) and the wall with marble incrustations (Fig. 9), where there is a high amount of information in green and red colors. In elements with complex geometry, such as the exedra, the iPad VR faces difficulties logging spatial properties; therefore, sizeable portions of the results are in green and red colors (Fig. 10).

5. Discussion

The comparison between the data acquired highlighted the potential of the photogrammetric approach, integrated with the SfM methods, and the iPad LiDAR camera, to collect reliable three-dimensional data on an architectural scale. In the operational phase, the difficulties due to any unforeseen relevant conditions can lead sometimes to gaps or inconsistencies in the data returned. This can also result in processing redundant data, with consequent data-management difficulties. Therefore, it is necessary to conduct a preliminary evaluation of the elements to establish the number of shots required for its registration; this can vary depending on the camera lens and the distance from the object. The iPad LiDAR camera, even if user friendly requires having good expertise as it might be necessary to repeat the data acquisition process to obtain a surveyed area without overlapping surfaces.

The laser scanners ensured greater reliability from an operational point of view, with obvious advantages both during the survey and data processing phases. The only limitation was the impossibility of scanning from different heights, and not having a scaffolding arrangement. From the data quality point of view, there is an obvious difference when comparing the results from an architectural and archaeological perspective. In the SfM, the object of study provides high-quality textured results compared to the model obtained from the laser scanner. The iPad LiDAR camera constructs a digital copy of the surveyed object, from which it is possible to obtain metric information with a satisfactory quality and an aesthetically approved result. However, the laser scanner is the methodology that best represents reality from a metric point of view.

6. Conclusions

The data acquisition survey project carried out on the Domus of the Calendar compared different survey methodologies: laser scanner, SfM and the iPad LiDAR camera. It consented to evaluate the qualitative level of data that can be reached by photogrammetric systems and portable devices, applied in a multi-scalar complicated archaeological context. The SfM has proven to be a reliable tool for representing the geometry of simple and complex elements. Due to its high accuracy, it can be used for representing elements that require a high quality of data, such as small archaeological objects. The iPad LiDAR is a tool that represents accurately the spatial information of elements of simple geometry. It can obtain the geometry of objects and spaces with relatively good precision. However, its use is not advisable in projects that require high-precision data. Its use is only advisable for representing volumes and shapes of archaeological and architectural objects that do not require a high level of precision.

The data acquisition comparison analysis shows that low-cost technologies like the SfM and the iPad LiDAR are reliable tools for representing physical space. Portable devices, due to their early stage of research and development, need to be improved to obtain a more precise and accurate representation of space. In the future, they will probably redefine the survey data acquisition process using digital tools, due to their versatility, intuitive use and information accessibility, as they provide the results almost instantaneously. These characteristics are in contrast with the SfM and the laser scanner, as they require a good level of expertise to be handled and long amount of time to process the information.

The possibility of producing different graphic restitution from the same three-dimensional models allows the conduct of analysis with data of different complexities. It was possible to correlate several phenomena that represent the entire architectural complex for different purposes: for example, as a diagnosis tool for planning potential restoring interventions.

The laser scanner is the only instrument that provides a reliable metric, geometric and morphological representation of a large complex like the Basilica of Santa Maria Maggiore. Smaller scale areas and objects can be chromatically and morphologically controlled using SfM and the iPad LiDAR. According to our research, the laser scanner gives the most accurate representation of a real object. In the comparison between the SfM and the iPad LiDAR, the SfM is the tool with the least uncertainty concerning to the numerical model acquired with the laser scanner.

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REFERENCES

Arrighetti A., Pansini R. (eds.) 2022, *Sistemi e tecniche di documentazione, gestione e valorizzazione dell'architettura storica. Alcune recenti esperienze*, «Archeologia e Calcolatori», 33, 1 (http://www.archcalc.cnr.it/journal/idyear.php?IDyear=2022-07-25).

Bianchini C., Inglese C., Ippolito A. 2016, *The Ancient Theatres of the Mediterranean as Integrated Survey Experience*, Roma, Sapienza Università Editrice.

Bianchini C., Inglese C., Ippolito A., Attenni M., Griffo M. 2022, *Un viaggio nelle Basiliche Romane: l'esperienza culturale dalla documentazione alla fruizione - A tour of the Roman Basilicas: The cultural experience from documentation to fruition*, in *Atti del II Convegno annuale/Proceedings of the 2nd Conference (Roma 2021)*, DTC Lazio Distretto tecnologico beni e attività culturali Centro di eccellenza, Roma, L'Erma di Bretschneider.

Dellepiane M., Dell'Unto N., Callieri M., Lindgren S., Scopigno R. 2013, *Archeological excavation monitoring using dense stereo matching techniques*, «Journal of Cultural Heritage», 3, 14, 201-210.

De Blaauw S. 2015, *Anomalous architecture: The case of Santa Maria Maggiore, Rome*, in *Digitizing Visual Memories in Architecture: Rome and Amsterdam Workshop*, Netherlands Institute for Advanced Study (Amsterdam 2015).

Ferdani D., Demetrescu E., Bottazzi G., Bigi P. 2022, *Il contributo dell'archeologia digitale allo studio e all'interpretazione dell'edilizia storica. Il caso di San Marino*, in Arrighetti, Pansini 2022, 181-200 (https://doi.org/10.19282/ac.33.1.2022.10).

Fiorini A. 2022, *Scansioni dinamiche in archeologia dell'architettura: test e valutazioni metriche del sensore LiDAR di Apple*, in Arrighetti, Pansini 2022, 35-54 (https://doi.org/ 10.19282/ac.33.1.2022.03).

Iannantuono K. 2010, *Aristocrazia e potere. La gens Neratia tra antico e tardoantico*, Tesi di Laurea, Università di Bologna.

Inglese C., Luchetti S. 2022, *Il mausoleo di Cecilia Metella tra documentazione grafica analogica e digitale: un approccio metodologico multidisciplinare*, in Arrighetti, Pansini 2022, 73-90 (https://doi.org/10.19282/ac.33.1.2022.05).

Ippolito A., Bartolomei C. 2014, *La gestione del dato di rilievo attraverso software open source: il sistema delle porte bolognesi*, in P. Giandebiaggi, C. Vernizzi (eds.), *Italian Survey & International Experience*, Roma, Gangemi, 897-906.

Liverani P. 1987, *L'ambiente nell'antichità*, in C. Pietrangeli (ed.), *La basilica romana di Santa Maria Maggiore*, Firenze, Nardini, 45-53.

Liverani P. 2010, *Osservazioni sulla domus sotto S. Maria Maggiore a Roma e sulla sua relazione con la basilica*, «Mitteilungen des Deutschen Archäologischen Instituts. Römische Abteilung», 116, 459-467.

Liverani P. 2013, *Alarico in Laterano e sull'Esquilino: due casi e qualche riflessione*, in J. Lipps, C. Machado, Ph. von Rummel (eds.), *The Sack of Rome in 410 AD. The Event, its Context and its Impact. German Archaeological Institute, Proceedings of the Conference (Rome 2010)*, Wiesbaden, Dr. Ludwig Reichert Verlag, 277-292.

Magi F. 1972, *Il calendario dipinto sotto Santa Maria Maggiore*, «Atti della Pontificia Accademia Romana di Archeologia», s. III, 11, 1, 1-102.

Remondino F. 2011, *Heritage recording and 3D modeling with photogrammetry and 3D scanning*, «Remote Sensing», 3, 104-1138.

Remondino F., El-Hakim S., Baltsavias E., Picard M., Grammatikopoulos L. 2008, *Image-based 3D modeling of the Erechteion, Acropolis of Athens*, «The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences», 37-B5, 1083-1091 (http://www.isprs.org/proceedings/XXXVII/congress/5_pdf/186.pdf).

Remondino F., Spera M.G., Nocerino E., Menna F., Nex F. 2014, *State of the art in high density image matching*, «The Photogrammetric Record», 29, 144-166.

Russo M., Manferdini A.M. 2015, *Integrated multi-scalar approach for 3D Cultural Heritage acquisitions*, in S. Brusaporci (ed.), *Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modelling, and Representation*, Hershey PA, Engineering Science Reference (IGI Global), 337-360.

Steinby E.M. 1995, *Lexicon topographicum urbis Romae*, II, *D-G*, Roma, Edizioni Quasar.

Steinby E.M. 1996, *Lexicon topographicum urbis Romae*, III, *H-O*, Roma, Edizioni Quasar.

Unesco W.H.C. 2021, *Historic Centre of Rome, the Properties of the Holy See in that City Enjoying Extraterritorial Rights and San Paolo Fuori le Mura* (https://whc.unesco.org/en/list/91/).

Vogt M., Rips A., Emmelmann C. 2021, *Comparison of iPad Pro®'s LiDAR and TrueDepth capabilities with an industrial 3D scanning solution*, «Technologies», 9, 25 (https://doi.org/10.3390/technologies9020025).

ABSTRACT

Data acquisition digital methodologies have become a reliable tool for surveying buildings with heritage values. Laser scanning has become the preferred method for performing 3D digital surveys because of its high accurate results; even though, the cost associated with it is usually high. Emerging technologies have been able to produce low-cost data acquisition methods, and they are currently being incorporated as part of digital survey projects. Using the Domus of the Calendar as a case study – an exceptionally unique archaeological and architectural site that was incorporated to the structural foundation system of the basilica of Santa Maria Maggiore – the present investigation aims to evaluate the data quality of two low-cost emerging technologies, namely SfM (Structure from Motion) and the iPad LiDAR system. This evaluation was developed by comparing low-cost technologies data acquisition capabilities with those of the laser scanner. The data for this test was obtained during an integrated survey campaign aimed at executing a critical analysis of the many historical layers of the Santa Maria Maggiore basilica. The results obtained from this investigation highlights the reliability of the different techniques implemented and suggest a useful solution for different and recurrent multi-scalar contexts.

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PHOTOGRAMMETRY FOR 3D REPRESENTATION OF HUMAN REMAINS FROM THE NECROPOLIS KR-N1 IN DHOFAR (SOUTHERN OMAN): DIGITAL TECHNOLOGY APPLIED TO OSTEO-ARCHAEOLOGICAL STUDIES

1. Introduction

The use of photogrammetry for 3D reconstruction in archaeology has increased significantly during the last ten years, becoming a fundamental tool for documentation, study (McCarthy 2014; Campana 2017; Jalandoni *et al.* 2018; Pena-Villasenin *et al.* 2019; Perez-Garcia *et al.* 2019; Valente 2019), protection and public fruition (Richardson 2013; Perez-Garcia *et al.* 2019) of archaeological sites and artefacts (Fiorini *et al.* 2017, 2019; Brandolini *et al.* 2020). If the application of this digital technology for 3D reconstruction of material culture seems to be definitively developed (Pierrot-Deseilligny *et al.* 2011; Dellepiane *et al.* 2013; Fryer, Chandler 2013; Galeazzi 2016; Sapirstein 2017; Brandolini, Patrucco 2019), its employment in the virtual recreation of osteo-archaeological evidence still remains episodic (Katz, Fries 2014; Jurda, Urbanova 2015, 2016a). Nevertheless, despite the scarce number of scientific publications, the importance of photogrammetry in osteo-archaeological studies is now acquired. Its application has been fundamental in recent research concerning the interpretation of bone modification marks caused by cutting (Gonzalez *et al.* 2015) or by taphonomic processes (Yravedra *et al.* 2017), demonstrating its importance also for forensic facial reconstruction (Moraes *et al.* 2014).

The employment of 3D photogrammetric reconstruction is still scarce in the archaeological contexts of Dhofar, the southernmost region of the Sultanate of Oman (Fig. 1). In this context, the pioneering work (Brandolini *et al.* 2020) conducted by the DHOMIAP Project, for the 3D model SfM-photogrammetric reconstruction of a dolmenic cist (D1), in the KR-N1 necropolis at Khor Kori (Lischi 2019; Lischi, Vangeli 2022) is noteworthy. This further confirmed the importance of photogrammetry during archaeological surveys of remote sites. To further expand this methodological test, a 3D photogrammetric reconstruction of a selected sample of human remains was chosen. This test was done with the aim of demonstrating, via a comparison of the results obtained by using two different settings (full-frame DSLR camera with macro lens vs. APS-C DSLR camera with standard zoom lens), the importance of this digital technology for the study, conservation and fruition of osteo-archaeological records in a poor state of preservation.

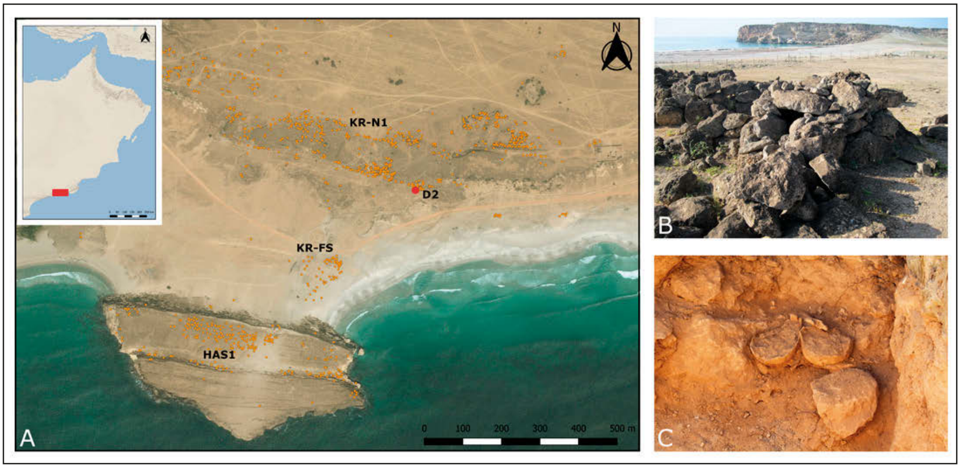

Fig. 1 – General location of the area (top left box), distribution of the necropolis KR-N1 with the location of the tomb under investigation and other archaeological evidence in the vicinity (A). Northeast view of tomb D2 before excavation (B); photo of two of the three skulls found during excavation of the tomb, still *in situ* (C).

The human bones selected for this test were found in one of the dolmenic cists (tomb D2) belonging to the KR-N1 necropolis (Fig. 1), a funerary setting on a promontory facing the sea in the Khor Rori area (Dhofar, Sultanate of Oman), five hundred metres N of the HAS1 settlement (dating from 4th century BC to 2nd century AD) (Lischi 2019, 2022), this being the pilot site for defining the Dhofar Coastal Culture (Lischi 2022). This newly identified culture led to a redefining of the land use and settlement dynamics in the Khor Rori area. Furthermore, it has allowed a new interpretation of the relations between the South Arabians settled in Sumhuram (ca. 2 km from HAS1) and the native inhabitants of the area.

Excavations at KR-N1, started in 2018 (Lischi 2018a, 2018b) by the DHOMIAP project and still ongoing, have determined the grave typologies, their distribution and a preliminary chronology for the use of the funerary structures (Lischi, Vangeli 2022). Three categories of tombs are attested: cairns, multiple cists and dolmenic cists, the latter ones being the most represented within the necropolis. Of the 558 dolmenic cists, only three (D1, D2, and D3) have been excavated. Radiocarbon dates, obtained from human bone fragments from D2, allowed at least to date the use of the necropolis at the beginning of the 4th century BC (Lischi, Vangeli 2022), coeval with the maximum expansion of HAS1 settlement (Lischi 2019, 2022).

After having studied in detail the osteological material from D2, four diagnostic elements have been selected for 3D photogrammetric reconstruction:

a fragment of male cranial frontal bone (specimen IQM18B.US124.HB1), an upper left first incisor (specimen IQM18B.US124.HB3), a calcific lymph node (specimen IQM18B.US124.HB51) and a right infant clavicle (specimen IQM18B.US124.HB21). All the selected specimens were characterised by significant elements. The cranial frontal bone had a subcircular healed injury. This cranial trauma is evidence of blunt force trauma, the origin of which is currently difficult to establish. However, it should be remembered that similar traumas have been found on coeval skeletons from Yemen and have been interpreted as possible ritual punishment (Coppa, Damadio 2005). The calcific lymph node could be the result of tuberculosis or brucellosis infections, the latter being more likely considering the agro-pastoral subsistence lifestyle of the HAS1 inhabitants (Lischi 2019, 2022). Finally, the incisor was affected by enamel hypoplasia and heavy wear, whilst the clavicle indicated a juvenile individual. The determination of the juvenile age of the individual to which the clavicle belonged was possible thanks to the lack of fusion of the medial epiphysis. This was also confirmed by comparing its length with the reference tables (Schaefer *et al.* 2008).

The images of the cranial frontal bone, the incisor and the lymph node were taken using a DSLR camera with a standard lens (referred to as Setting 1), while the images of the clavicle were taken using a full-frame DSLR camera with a macro-lens (referred to as Setting 2). The four selected elements, being part of the whole osteo-archaeological record of tomb D2, were in a poor state of preservation. The application of 3D photogrammetric reconstruction techniques has also provided an opportunity for verifying the efficiency of this method for studying fragile human remains, avoiding further physical manipulation.

2. Methods and tools: image acquisition

Setting 1 image acquisition made use of a DSLR camera (Nikon D3400), operated in automatic mode with a standard zoom lens (DX VR AF-P NIKKOR 18-55 mm 1:3.5-5.6 G) (Tab. 1). Setting 2 image acquisition made use of a full-frame DSLR camera (Nikon D610), operated in manual mode with a macro-lens (AF-S Micro NIKKOR 60 mm 1:2.8 G ED) (Tab. 1).

The time spent to obtain the images with Setting 1 was about 15 minutes per element (for a total of 45 minutes), while 30 minutes were necessary to acquire images with Setting 2. The description that follows is shared by both Setting 1 and Setting 2. To avoid micro-motion effects, a tripod was used to sustain the camera, which was operated using a wireless remote control. The image acquisition was realised by placing the bones on a turning plate inside a cubic box with a black background, and by illuminating it with two external lamps of neutral colour temperature (5560 K). The distance in centimetres between the two sights was used as the metric reference during the creation

	Setting 1	Setting 2
Device	Nikon D3400	Nikon D610
Lens	Standard 18-55mm	Macro-lens 60 mm
Number of elements	3	1
Picture acquisition time (total)	~45 minutes	~30 minutes
Exposure time	1/6 s	1/20 s
Aperture	f/6.3	f/25
Shooting mode	Remote control, 2 s	Remote control, 2 s
Exposure mode	A	M
White balance	A, 5560 K	M, 5560 K
ISO	100	250-400

Tab. 1 – Features used for Setting 1 and 2.

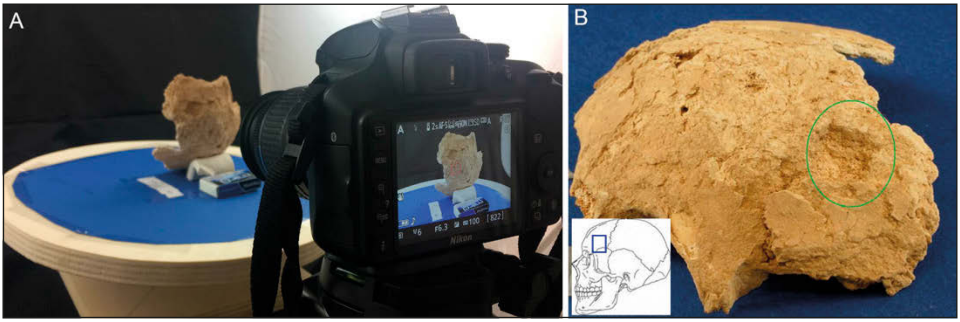

Fig. 2 – A) Camera workstation during the frontal bone image acquisition; B) frontal bone with the lesion highlighted in green and the position of the lesion on the cranial district (bottom left).

of the scale-bar. Several series were made, with the lens at different heights, to obtain as much information as possible about the osteological elements (Fig. 2).

The first series was realised with the lens almost parallel to the plane above which the object was located. The second series was taken with the lens at the same height, while different positioning of the subject allowed documentation of the other parts. For the third series, the lens was set at a greater height and was inclined to the object's plane. The fourth series, only realised with Setting 1, was obtained by changing only the object position. In total, 428 images were taken: 95 for the cranial frontal bone, 76 for the incisor, 98 for the lymph node and 159 for the clavicle. Pictures were saved in RAW format, eventually converting them into TIFF format through the software ViewNX2. Then, the TIFF images were uploaded in a chunk (working folder) of the software Agisoft Metashape Professional (1.7.5 version) to start the desk processing.

3. Methods and tools: desk processing

The desk processing methodology summarised below is common to both Settings 1 and 2. Images were processed through the software Agisoft Metashape Professional (1.7.5 version), using the virtual machine (GPU Tesla T4 2 CPU and 384Gb of RAM 800 GB of disk) kindly made available by Laboratorio MAPPA (Metodologie APPlicate all'Archeologia) of the University of Pisa. The process consists of five operations:

1) Creation of masks. The masks were created with high precision to reduce noise to a minimum. In this process, the chromatic contrast between the colour of the bones (whitish) and that of the cardboard (blue) allowed the application of the 'intelligent scissors' function of the software that speeded up the workflow.
2) Camera alignment and creation of the sparse point cloud. The images were aligned by selecting a high level of proceeding accuracy with the key point limit set to 100,000 and the tie point limit to 4000.
3) Creation of the scale-bar. The error margin for the creation of the scale-bar was set to 0.001 m because of the small dimension of the subjects.
4) Creation of the dense point cloud and creation of the mesh. The dense point cloud, created by setting high quality and medium deep filtering, was used as the source of information for the creation of the mesh.
5) Creation of the 3D model and of the texture. After the creation of the mesh, the 3D model with the texture is created. The texture itself was created by selecting the images as the source of information and setting the ratio texture size/count to 4,096×1. The mapping mode was set to 'generic', and the blending mode to ' mosaic', while the additional parameters (Enable Hole Filling and Enable Ghost Filter) were not added. The parameters described above are summarised in Tab. 2.

4. Pros and cons of Setting 1 and Setting 2

The first setting, as previously mentioned, was accomplished using a Nikon D3400 DSLR camera with an 18-55 mm standard zoom lens set to

3D model and texture creation parameter	
Source of information	Images
Texture size/count	4096x1
Mapping mode	Generic
Blending mode	Mosaic
Enable hole filling	Not
Enable ghost filter	Not

Tab. 2 – 3D model and texture creation parameter.

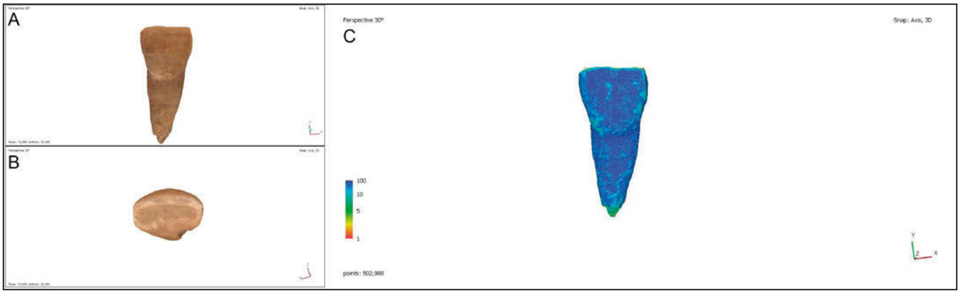

Fig. 3 – Enamel hypoplasia lines and wear on the buccal and occlusal view of the incisor (A, B); high degree of confidence of the incisor dense point cloud (C).

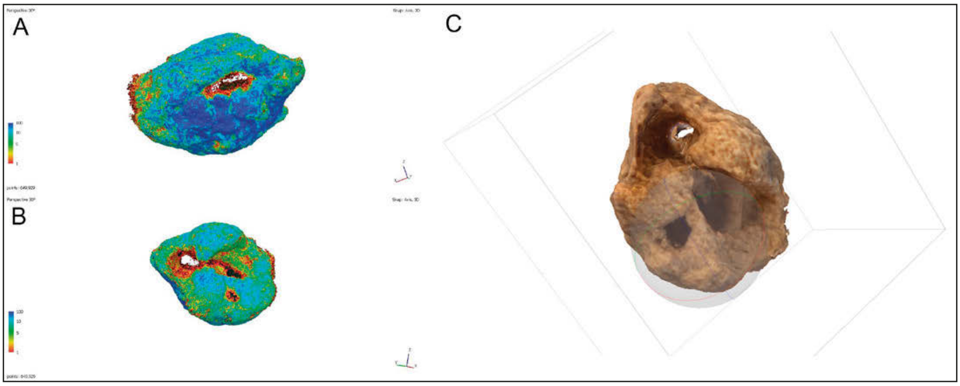

Fig. 4 – Low degree of irregular-shape portion of the lymph node dense point cloud (A, B); undetailed texture of the lymph node result of the low confidence of the dense point cloud (C).

automatic mode. This setting was utilized to capture images of the frontal bone, incisor, and lymph node, and allowed for quick acquisition of the three elements in approximately 45 minutes. The automatic mode eliminated the need to manually adjust exposure and focus settings, and the high depth of the lens expedited the process. A specialized operator was not required to use this setting due to its simplicity and speed.

The standard zoom lens provided detailed images, even capturing barely visible traces on the remains, such as enamel hypoplasia and wear traces, which were clearly visible in the 3D model of the incisor (Fig. 3). The dense cloud confidence was also high, indicating the effectiveness of Setting 1 for 3D reconstruction of small human remains. Additionally, the economic aspect of this process was advantageous as the standard zoom lens is typically included in the basic equipment of any DSLR camera. However, the standard zoom lens

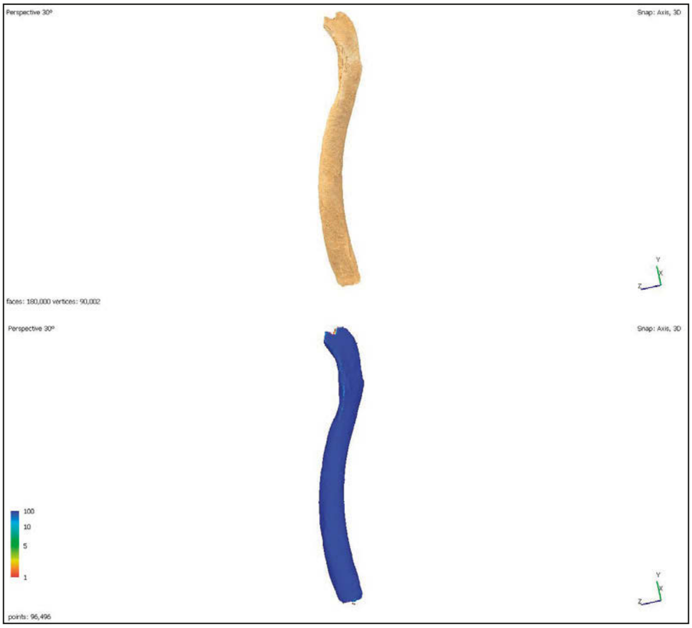

Fig. 5 – High quality of the clavicle texture resulted from the high degree of confidence of the dense point cloud (top); high degree of confidence of the clavicle dense point cloud (bottom).

was not suitable for irregular-shaped and small-sized elements, as demonstrated in the photogrammetry of the lymph node. The dense cloud confidence was low, resulting in a non-detailed texture of those areas (Fig. 4). To avoid losing essential information during osteo-archaeological studies, it is best to avoid using standard zoom lenses for 3D reconstruction of irregular-shaped objects like the lymph node. The pros and cons of Setting 1 are summarized in Tab. 3.

In contrast, Setting 2 utilized a Nikon D610 full-frame DSLR camera with a 60 mm macro lens set to manual mode. The image acquisition of the clavicle was made with this setting, which required manual control of light exposure and focus. This resulted in a longer acquisition time of approximately 40 minutes, and either an operator with photographic skills or an operator willing to invest a lot of time to improve this technique was needed.

Although Setting 2 was more expensive due to the need for a full-frame DSLR camera with a macro lens, its excellent degree of detail was noteworthy. The 3D model of the clavicle showed almost no zones of low confidence in the dense point cloud, which was crucial for the subsequent texture to have colours equal to those of nature (Fig. 5). The pros and cons of Setting 2 are summarized in Tab. 3.

	Setting 1	Setting 2
Pros	- Speed of execution - No need for specialized worker - Not expensive technique - Good detail of small remains - Good detail of scarcely visible traces	- No zone of low confidence in the dense point cloud - Perfect colour texture
Cons	- Not high degree of detail of the "shape anomalies" of small-size elements	- Slowness of execution - Specialized worker request - Expensive technique

Tab. 3 – Comparison between Pros and Cons of Setting 1 and 2.

5. Results and discussion

The results obtained by applying both settings were significant from different points of view, providing valuable insights into the study of osteological samples. The high degree of detail captured in the 3D models allowed for thorough examination without the need for additional physical manipulation. This aspect is crucial not only for the preservation of osteological materials but also for the possibility of studying them remotely, in a different location or country from where they are stored, as was the case in this study. One notable advantage of the 3D models was the exceptional precision of the scale-bar, enabling accurate measurements for anthropometric studies and analysis of morphological variables, as is clearly visible in the case of teeth. Measurements such as clavicle length, the circumference of the frontal bone lesion, mesio-distal and bucco-lingual diameters, and crown and root heights of the incisor (Fig. 6) could all be taken with great precision. A comparison between manual measurements using a digital calibre and digital measurements is presented in Tab. 4.

It can be observed that, in general, the digital measurements are generally higher than those obtained through manual measurement, with a difference ranging between 0.19 and 0.75 mm. Only in one instance did the difference become negative, but it remained well below 1 mm (-0.30 mm). Interestingly, the digital measurements that closely matched the manual measurements were predominantly obtained from the models produced with Setting 1, while the only measurement taken on a 3D model produced with setting 2 differed from the manual measurement by 0.75 mm. Furthermore, the high-quality 3D model of the incisor enabled the measurement of the line of enamel hypoplasia. These lines serve as a permanent chronological record of stressful

Inventory n.	Description	Manual measurements (mm)	Digital measurements (mm)	Deviation % between the two techniques	Setting
IQM18B.US124.HB21	Clavicle maximum length	670	675	+ 0,75	2
IQM18B.US124.HB3	M-D incisor diameter	7,92	7,95	+ 0,38	1
IQM18B.US124.HB3	B-L incisor diameter	4,17	4,18	+ 0,24	1
IQM18B.US124.HB3	Crown lingual height	6,60	6,58	- 0,30	1
IQM18B.US124.HB3	Root lingual height	102,8	103	+ 0,19	1

Tab. 4 – Comparison between manual measurements and digital measurements.

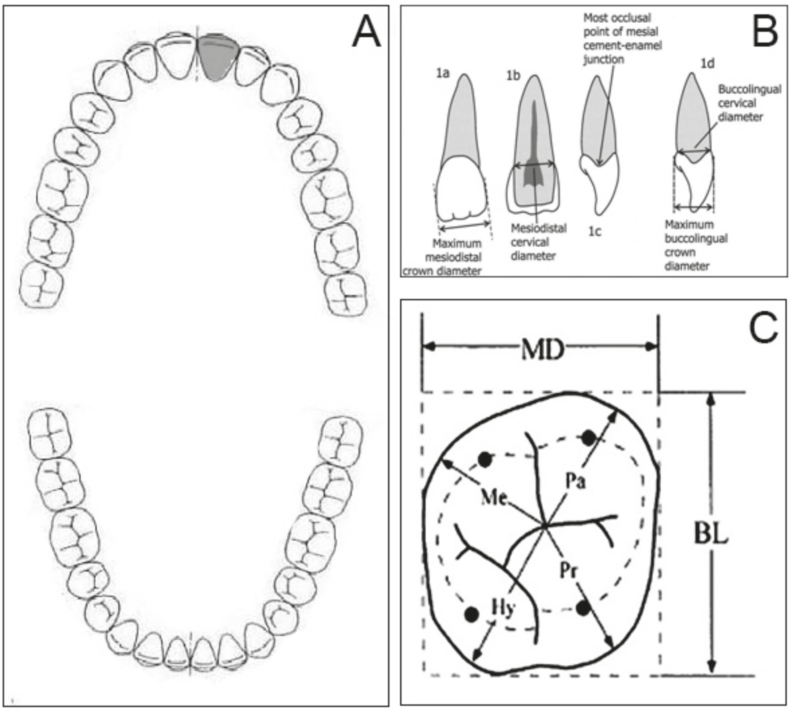

Fig. 6 – Adult teeth scheme with IQM18B.US124.HB3 position highlighted (A); mesio-distal and bucco-lingual crown and cervical diameters (B) (after Hillson *et al.* 2005); diagram showing mesio-distal width and bucco-lingual width (C).

events, often nutrition-related, that occurred during the first seven years of the individual's life (Goodman, Rose 1990). Within tomb D2, four episodes of enamel deposition disruption between the first and third year of the buried individual's life were discovered (Vangeli 2022). One particularly evident line was prominently visible in the 3D model presented in this study (Fig. 3), allowing for accurate measurement and identification of the time when the individual experienced significant nutritional stress, approximately at 1.49 years of age.

The regression equation proposed by Goodman, Rose (1990) allowed the determination of this value. Normally, this type of measurement requires the use of a microscope, which implies the transportation of the material to a laboratory equipped with such an instrument. Unfortunately, this is not always feasible, highlighting the usefulness of creating 3D models in the field. Such models enable the measurement of highly diagnostic elements, like enamel hypoplasia lines, which can be challenging to be accurately measured using portable instruments such as a caliper.

Additionally, within our case studies, as previously described, a 3D model of a calcified lymph node (IQM18B.US124.HB51) was created. This lymph node is believed to be pathognomonic of brucellosis, although it could also be indicative of another infection such as tuberculosis. The definitive assessment of the nature of the infection suffered by the individual requires destructive biomolecular analysis. Therefore, the ability to preserve a 3D model of the fragment becomes crucial as it allows for the continued study of its morphology even after its destruction, enabling researchers to gather additional data about the infection. The results obtained by applying both settings in this study underscored how photogrammetry could serve as a viable alternative to laser scanners, especially when it comes to reconstructing 3D models of small human remains (Jurda, Urbanova 2016a).

From a methodological standpoint, our research focused on testing two different settings (Setting 1 and Setting 2) to compare the effectiveness of basic equipment against more expensive and technologically advanced photographic tools. While there are various other combinations of cameras, lenses, and acquisition modes worth exploring, such as using an APS-C DSLR camera equipped with a macro lens or operating either an APS-C or full-frame DSLR camera with a macro lens in automatic mode, our main objective was to evaluate the potential of the most basic and user-friendly photographic equipment (Setting 1) versus the most advanced and costly equipment (Setting 2), rather than covering all possible combinations and settings.

As previously mentioned, Settings 1 and 2 differed primarily in the devices used while keeping the image acquisition process largely unchanged, except for the additional fourth series in Setting 1. The use of a DSLR Nikon D3400 with a standard zoom lens in automatic mode significantly accelerated the image acquisition process in Setting 1 compared to the manual mode employed in Setting 2. The manual mode required more attention to control lighting and focus on the subject. The resulting 3D models clearly exhibit varying levels of detail. The macro lens used in Setting 2, with its technical specifications, enabled precise focusing at close distances, resulting in highly defined details, as exemplified in the 3D model of the clavicle. However, even the application of a standard lens in Setting 1 yielded a considerable degree of detail, as evident in the rendering of the incisor enamel hypoplasia and wear. Nonetheless, Setting 1 may not be suitable for elements with highly irregular surfaces, such as the documented lymph node, where Setting 2 is undoubtedly more appropriate.

The ability to conduct osteo-archaeological studies without physically handling human remains holds paramount importance for poorly preserved osteological specimens. As highlighted by Mccorriston *et al.* (2012), the inadequate preservation state of human remains is a major obstacle preventing the comprehensive study of many funerary contexts in Dhofar. 3D model reconstruction presents a promising solution to this challenge. Creating 3D models can prevent progressive fragmentation, destruction, and the loss of information associated with skeletal elements, stimulating scholars' exploration of Dhofar's funerary archaeology. Additionally, 3D model reconstruction enables the visualization of osteo-archaeological features without the need for their physical presence, eliminating the necessity of transporting fragile remains across countries for research purposes. Therefore, generating 3D models of osteological elements has the potential to enhance the accessibility and utilization of valuable information in this field.

6. Conclusions

The objective of this paper was to test and compare two different settings for the 3D model reconstruction of human remains, aiming to demonstrate the significance of 3D photogrammetry in studying osteo-archaeological records, particularly those in a poor state of preservation. The findings revealed that Setting 1 offered a balance between good quality and fast execution speed, making it highly relevant for the 3D photogrammetry of *in situ* skeletal remains. This setting proved valuable for describing taphonomic processes, documenting specimens, and capturing different excavation phases (Lussu, Marini 2020). Such documentation is crucial considering the potential damage caused to the osteo-archaeological record during its removal from the ground matrix. Preserving the ability to document the funerary context from which the 3D reconstructed human bones originate is of utmost importance in gaining a comprehensive understanding of their history. This emphasis on contextualization aligns with the principles of modern South Arabian bio-archaeology, which seeks to surpass the traditional approach of isolated laboratory-based anthropological research (Williams *et al.* 2014).

On the other hand, Setting 2 yielded excellent results in terms of capturing intricate details of human bones, but it involved higher costs, increased complexity in operation and longer processing times. Under optimal conditions, Setting 2 proved particularly suitable for more ambitious objectives, such as reconstructing facial morphology or determining sex and ancestry (Jurda, Urbanova 2016b). However, the application of 3D photogrammetry in these specific fields remains relatively limited (Lussu, Marini 2020). The higher level of detail provided by Setting 2 becomes especially valuable when there is a need to produce a 3D printed model of an osteo-archaeological element, particularly irregular-shaped ones (Cole *et al.* 2019).

This comparative test highlighted the advantages and disadvantages of the two different settings, clarifying their specific use adequacy. The optimal quality-speed ratio offered by Setting 1 was deemed sufficient for accurate 3D documentation of human remains and their funerary context. However, it is worth exploring a potential alternative in the future, such as employing a DSLR camera (either APS-C or full-frame) equipped with a macro lens and operated in automatic mode. This setup could potentially eliminate the complexity and slowness associated with Setting 2 while maintaining a high level of image detail. However, it should be noted that the limited depth of field inherent to macro lenses would require capturing more photographs compared to Setting 1, making the latter still the faster option. Despite their specific characteristics and applications, both settings reaffirmed the significance of 3D photogrammetry in the bio-archaeological study of human remains, particularly those in a poor state of preservation.

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REFERENCES

Brandolini F., Cremaschi M., Degli Esposti M., Lischi S., Mariani G.S., Zerboni A. 2020, *Sfm-Photogrammetry for fast recording of archaeological features in remote areas*, «Archeologia e Calcolatori», 31, 2, 33-45 (https://doi.org/10.19282/ac.31.2.2020.04).

Brandolini F., Patrucco G. 2019, *Structure-from-Motion (SfM) photogrammetry as a non-invasive methodology to digitalize historical documents: A highly flexible and low-cost approach?*, «Heritage», 2, 2124-2136.

Campana S. 2017, *Drones in archaeology. State-of-the-art and future perspective*, «Archaeological Prospection», 24, 4, 275-296.

Cole G., Kingham E., Waldron T. 2019, *Printing pathology: A case study in presenting pathological human skeletal remains for education and display*, «Journal of the Institute of Conservation», 42, 1, 18-33.

Coppa A., Damadio S. 2005, *Paleobiology of the populations of Yemen*, in A. de Maigret, S. Antonini (eds.), *South Arabian Necropolises. Italian Excavations at Al-Makhdarah and Kharibat al-Ahjur*, Roma, ISIAO, 91-113.

Dellepiane M., Dell'unto N., Callieri M., Lindgren S., Scopigno R. 2013, *Archaeological excavation monitoring using dense stereo matching techniques*, «Journal of Cultural Heritage», 14, 201-210.

Fiorini A., Curci A., Benazzi S., Spinapolice E.E. 2017, *Il sistema di documentazione digitale dello scavo archeologico nel sito di Uluzzo C (Nardò, LE)*, «Museologia Scientifica e Naturalistica», 13, 68-70.

Fiorini A., Curci A., Spinapolice E.E., Benazzi S. 2019, *Grotta di Uluzzo C (Nardò-Lecce): risultati preliminari, strumenti e metodi dell'indagine archeologica*, «FOLD&R Fasti On Line Documents & Research», 440, 1-18 (https://www.fastionline.org/micro_view.php?item_key=fst_cd&fst_cd=AIAC_4590).

Fryer J.G., Chandler H.H. 2013, *AutoDesk 123D Catch: How accurate is it?*, «Geomatics World», 32-33.

Galeazzi F. 2016, *Towards the definition of best 3D practices in archaeology: Assessing 3D documentation techniques for intra-site data recording*, «Journal of Cultural Heritage», 17, 159-169.

Gonzalex Mate M.A., Yravedra J., Gonzalez-Aguilera D., Palomeque-Gonzalez J.F., Dominguez-Rodrigo M. 2015, *Micro-photogrammetric characterization of cut marks on bones*, «Journal of Archaeological Science», 62, 128-142.

Goodman A.H., Rose J.C. 1990, *Assessment of systemic physiological perturbations from dental enamel hypoplasias and associated histological structures*, «Yearbook of Physical Anthropology», 33, 59-110.

Hillson S., Fitzgerald C., Flinn H. 2005, *Alternative dental Measurements: Proposals and relationships with other measurements*, «American Journalof Physical Anthropology», 126, 413-426.

Jaladoni A., Domingo I., Tacon P.S.C. 2018, *Testing the value of low-cost Structure-from-Motion (SfM) photogrammetry for metric and visual analysis of rock art*, «Journal of Archaeological Science», 17, 605-616.

Jurda M., Urbanova P. 2015, *Sexual dimorphism in human crania from the perspective of 3D mesh-to-mesh comparison tools*, 7th European Academy of Forensic Science Conference, conference paper.

Jurda M., Urbanova P. 2016a, *Three-dimensional documentation of Dolnì Vestonice skeletal remains: Can photogrammetry substitute laser scanning?*, «Anthropologie», 2, 109-118.

Jurda M., Urbanova P. 2016b, *Sex and ancestry assessment of Brazilian crania using semi-automatic mesh processing tools*, «Legal Medicine», 23, 34-43

Katz D., Friess M. 2014, *Technical note: 3D from standard digital photography of human crania-A preliminary assessment*, «American Journal of Physical Anthropology», 154, 152-158.

Lischi S. 2018a, *Fourth and fifth season of the Italian mission to Oman (IMTO) in the site of Inqitat-Khor Rori archaeological site, Dhofar, Sultanate of Oman*, not published.

Lischi S. 2018b, *Necropolis KR-N1 in the Area of Khor Rori, Dhofar (Sultanate of Oman). Report on the 2018 Preliminary Field Season*, not published.

Lischi S. 2019, *Risultati preliminari delle ricerche archeologiche presso l'insediamento HAS1 di Inqitat, Dhofar (2016-2019)*, «EVO», 62, 119-133.

Lischi S. 2022, *Settlement Dynamics and Territorial Organisation in Dhofar between the Bronze Age and Late Antiquity. Understanding the Settlement Process of the Khor Rori Area and Development of a New Regional Cultural Model*, PhD thesis, not published.

Lischi S., Vangeli M. 2022, *An Iron Age necropolis (KR-N1) in the area of Khor Rori: New discoveries about the coastal culture of Dhofar*, «The IASA Bulletin», 29, 16-17.

Lussu P., Marini E. 2020, *Ultra close-range digital photogrammetry in skeletal anthropology: A systematic review*, «PLOS ONE», 15, 4.

McCarthy J. 2014, *Multi-image photogrammetry as a practical tool for cultural heritage survey and community engagement*, «Journal of Archaeological Science», 43, 175-185.

Mccorriston J., Harrower M., Steimer-Herbet T., Williams K.D., Senn M., Al Hadhari M., Al Kathiri M., Al Kathiri A., Saliège J.-F., Everhart J. 2012, *Monuments and landscape of mobile pastoralist in Dhofar: The Arabian Human Social Dynamics (AHSD) Project, 2009-2011*, «Journal of Oman Studies», 12, 117-144.

Moraes C., Miaomoto P., Melani R.F.H. 2014, *Demonstration of protocol for computer-aided forensic facial reconstruction with free software and photogrammetry*, «Journal of Research in Dentistry, Acoustics, Speech, and Signal Processing Newsletter, IEEE», 2, 1, 77-90.

Pena-Villasenin S., Gil-Docampo M., Ortiz-S. J. 2019, *Professional SfM and TLS vs a simple SfM photogrammetry for 3D modelling of rock art radiance scaling shading in engraving detection,* «Journal of Cultural Heritage», 37, 238-246.

Perez-Garcia J.L., Mozas-Calvache A.T., Barba-Colmenero V., Jimenez-Serrano A. 2019, *Photogrammetric studies of inaccessible sites in archaeology: Case study of burial chambers in Qubbet el-Hawa (Aswan, Egypt)*, «Journal of Archaeological Science», 102, 1-10.

Pierrot-Deseilligny M., De Luca L., Remondino F. 2011, *Automated image-based procedures for accurate artifacts 3D model and orthoimage*, «Geoinformatics FCE CTU», 6, 291-299.

Richardson L. 2013, *A digital public archaeology?*, «Institute of Archaeology», 23, 1-12.

Sapirstein P. 2017, *Appendices: A high precision photogrammetric recording system for small artifacts*, «Journal of Cultural Heritage», 31, 33-45.

Schaefer M., Black S., Scheuer L. 2008, *Juvenile Osteology: A Laboratory and Field Manual*, London, Academic Press.

Valente R. 2019, *Digital workflow to improve osteoarchaeological documentation*, «Digital Applications in Archaeology and Cultural Heritage», 13, 1-10.

Vangeli M. 2022, *Pratiche funerarie in Arabia Meridionale tra l'Età del Bronzo e il periodo classico: il caso-studio della necropolis KR-N1 in Dhofar (Oman)*, Thesis, Unpublished.

Williams K.D., Steimer-Herbet T., Gregoricka L.A., Saliège J.-F., Mccorriston J. 2014, *Bioarchaeological analysis of 3rd millennium BC high circular tower tombs from the Arabian Human Social Dynamics (AHSD) Project in Dhofar, Oman*, «Journal of Oman Studies», 12, 153-172.

Yravedra J., Garcia-Vargas E., Mate-Gonzalez M.A., Aramendi J., Palomeque-Gonzalez J.F., Valles-Iriso J., Matesanz-Vicente J., Gonzalez-Aguilera D., Dominguez-Rodrigo M. 2017, *The use of micro-photogrammetry and geometric morphometrics for identifying carnivore agency in bone assemblages*, «Journal of Archaeological Science», 14, 106-115.

ABSTRACT

The poorly preserved human bones discovered during the DHOMIAP Project excavation of the necropolis KR-N1 in the area of Khor Rori (Dhofar, Sultanate of Oman) were an opportunity to apply, for the first time in Dhofar's pre-Islamic funerary contexts, 3D photogrammetry to osteo-archaeological studies. The low economic engagement and the execution speed make this technique essential in the documentation of barely accessible archaeological remains and contexts, as already witnessed by previous studies conducted outside this research area. This paper aims to find a more appropriate method and setting for 3D model photogrammetric reconstruction of human remains, demonstrating the importance of this digital technology for the study of poorly preserved osteo-archaeological remains. For these purposes, the results obtained using two different settings for image acquisition (one with macro and one with standard lens) were compared and discussed.

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MAGOH: UN NUOVO STRUMENTO PER LA GESTIONE E LA CONSULTAZIONE DEI DATI ARCHEOLOGICI DEL NORD DELLA TOSCANA*

1. Premessa

Il progetto MAGOH[1] (Managing Archaeological data for a sustainable Governance of Heritage) nasce come progetto di ricerca (2021-2023) finanziato nell'ambito dei fondi POR FSE 2014-2020 della Regione Toscana, mediante una collaborazione diretta tra il Laboratorio MAPPA (Metodologie digitali APPlicate all'Archeologia) dell'Università di Pisa, le Soprintendenze Archeologia, Belle Arti e Paesaggio (SABAP) per la città metropolitana di Firenze e le province di Pistoia e Prato e per le province di Pisa e Livorno, le PMI Inera srl e Miningful srls. La sfida alla base del progetto era quella di rispondere alle necessità delle due SABAP nell'ambito della semplificazione e gestione dei dati di archivio quotidianamente utilizzati per espletare le pratiche di tutela e valorizzazione del territorio. Tutti questi dati sia in formato cartaceo, sia digitale non sono mai stati amministrati attraverso strumenti informatici che ne gestiscano le diverse tipologie (testuale, cartografica e fotografica) e ne consentano sia un ancoraggio al territorio da cui provengono, sia una consultazione simultanea. Il progetto, quindi, si è prefisso di rilasciare una piattaforma che permetta di visualizzare e visionare l'intero ciclo della documentazione archeologica, partendo dalla digitalizzazione dell'archivio cartaceo delle soprintendenze e dall'acquisizione dei dati già digitalizzati, fino ad arrivare alla visualizzazione integrata dei singoli interventi archeologici.

I comuni coinvolti sono 103 per un territorio che ricopre ca. 7200 km^2 (Fig. 1). Su richiesta delle stesse SABAP, sono stati esclusi il comune metropolitano di Firenze e il comune di Volterra. L'obiettivo finale è stato quello di fornire uno strumento di lavoro che agevolasse le quotidiane attività di tutela e valorizzazione in capo ai funzionari delle soprintendenze, partendo dalle loro esigenze e tenendo conto del loro *modus operandi* ormai consolidato (Anichini *et al.* 2021a). Inoltre, tale strumento si pone come contenitore utile per le attività di ricerca di studiosi e di professionisti operanti in ambito storico-archeologico incaricati di redigere relazioni di rischio archeologico (VPIA) o di effettuare indagini archeologiche, per le attività di tutela e controllo del territorio degli Enti Locali, ma anche per la semplice consultazione di dati storico-archeologici da parte dei cittadini.

* A.R. Saponara ha curato la stesura complessiva della prima bozza del paper, F. Anichini e G. Gattiglia ne hanno curato la revisione e la stesura del paragrafo finale. Direzione Scientifica di Maria Letizia Gualandi, coordinamento di Gabriele Gattiglia e Francesca Anichini, collaborazione dei funzionari archeologi Pierluigi Giroldini (SABAP-FI) e Claudia Rizzitelli (SABAP-PILI).

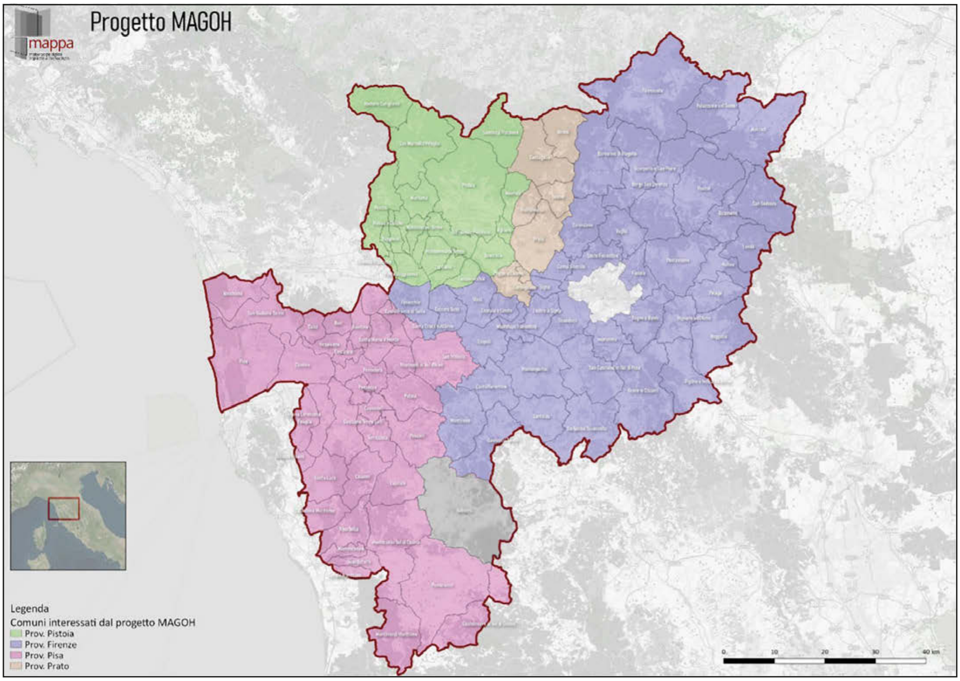


Fig. 1 – Area di indagine del Progetto MAGOH.

2. Da MAPPA a MAGOH

Il Progetto MAGOH si è sviluppato a partire dal decennale lavoro iniziato nel 2011 con il progetto MAPPA (Metodologie Applicate alla Predittività del Potenziale Archeologico), che ha visto la creazione e il popolamento di un sistema webGIS integrato, denominato MAPPAgis, in cui sono convogliati, nella loro completa diacronia (dalla preistoria all'età contemporanea) tutti i dati archeologici, paleoambientali e di cartografia storica relativi all'area urbana del Comune di Pisa, e ne ha mantenuto la filosofia e la modalità di strutturazione del dato archeologico (Anichini *et al.* 2012, 2013), ampliando la base territoriale e tralasciando (almeno per il momento) la fase predittiva. In questo decennio, l'applicativo MAPPA è stato utilizzato come strumento per la tutela e la gestione del territorio urbano a opera dei funzionari archeologi della SABAP di Pisa. Questa continua fruizione è stato il primo incentivo all'ideazione di un sistema che ampliasse gli orizzonti oltre la città, per affrontare una visione del dato archeologico estesa anche al territorio extraurbano.

Il Progetto MAGOH è partito, quindi, da una metodologia consolidata di analisi e formalizzazione del dato archeologico basato sulla strutturazione delle informazioni contenute nella letteratura grigia (report di scavi, documenti d'archivio, note e rapporti di funzionari, etc.) in interventi archeologici, individuati su base spaziale e temporale (Anichini *et al.* 2012, 57-61), ma si è sviluppato per abbracciare un territorio più vasto, caratterizzato dalla presenza di evidenze archeologiche peculiari e tipologicamente diversificate, legate a complessi sviluppi storici e a una conformazione territoriale variegata che dalla costa tirrenica arriva fino all'Appennino Tosco-Emiliano. Il Progetto ha riguardato: 1) la digitalizzazione dei dati di archivio; 2) la creazione e il popolamento dell'applicativo web-based integrato; 3) la creazione del front end per la fruizione e divulgazione dei dati.

3. Digitalizzazione dei dati di archivio

Una delle fasi più lunghe e articolate è stata l'acquisizione dei documenti conservati presso l'Archivio della SABAP-Firenze (già Soprintendenza Archeologica della Toscana), situato a Firenze e dal 2016 sotto la giurisdizione del Polo Museale (Arbeid *et al.* 2020, 73). Il protrarsi oltre quanto inizialmente stimato di questa fase, durata complessivamente 12 mesi, è stato causato dalle restrizioni dovute alla pandemia da Covid-19, con un'alternanza tra periodi di lockdown e fasi di accesso contingentato che hanno costretto a una revisione in corso d'opera delle modalità di acquisizione dei materiali. I documenti conservati in archivio sono raggruppabili in 6 sezioni:

– l'archivio cartaceo, che comprende l'archivio storico (1960-1988) e l'archivio di deposito (1989-primo semestre 2006);
– la documentazione acquisita mediante il protocollo informatico EsPI, in parte digitalizzata e in parte cartacea (secondo semestre 2006-primo semestre 2016);
– l'archivio disegni;
– l'archivio fotografico;
– l'archivio CD;
– la documentazione acquisita attraverso il protocollo G.I.A.D.A. (Gestione Integrata Archiviazione Documentale Avanzata), il sistema di protocollo informatico e di gestione documentale digitale rilasciato a metà del 2016 e tuttora in uso.

La documentazione cartacea fino al 1960 conservata nell'archivio fiorentino è stata oggetto di un progetto di digitalizzazione da parte dell'allora Soprintendenza Archeologica della Toscana in collaborazione con l'Archivio di Stato di Firenze tra il 2015 e il 2016. Il lavoro ha riguardato la scansione completa del *corpus* più antico (anni 1872-1924) e dei documenti conservati sotto la posizione archivistica di protocollo "9-Scavi e scoperte archeologiche" prodotti dal 1924 al 1960 (compreso). Il Progetto MAGOH ha, quindi, acquisito la restante documentazione cartacea fino al 2006, limitandosi alla posizione archivistica riguardante attività archeologiche, "9-Monumenti, musei, scavi, bellezze naturali". Inizialmente, la digitalizzazione è stata eseguita su tutti i documenti presenti nei faldoni cartacei; successivamente, a causa dello stop dovuto alla pandemia, è stato necessario focalizzarsi esclusivamente sul dato prettamente archeologico, limitandosi alla digitalizzazione dei documenti di scavo, alle relazioni di missione/sopralluogo, alle assistenze archeologiche, alle VIArch e VPIA, ai nullaosta, ai pareri, etc.

Contemporaneamente, è stata consultata e acquisita la documentazione contenuta all'interno del protocollo informatico EsPI, in uso fino alla metà del 2016. Il sistema era organizzato in modo tale che per ogni argomento o Titolo si creasse un codice alfanumerico; all'interno di ogni Titolo erano presenti le cartelle per Provincia, per singolo Comune e per grandi opere (ad es. scavi per il posizionamento di cavi ENEL o per il metanodotto SNAM). Tra gli innumerevoli titoli, sono stati, quindi, individuati quelli maggiormente attinenti alla documentazione archeologica all'interno del comparto "TUTELA 34.00.00":

– 34.01.00_Normative quesiti pareri;
– 34.07.00_Individuazione dei beni:
  34.07.01_Verifica Interesse Culturale;
– 34.19.00_Valutazione Interventi e Progetti:
  34.19.04_Opere di Pubblica Utilità e Infrastrutture;
  34.19.07_Opere di Interesse Privato;
– 34.31.00_Ritrovamenti e scoperte:
  34.31.01_Scavi e rinvenimenti;
  34.31.07_Concessioni;
– 34.34.31_Scavi clandestini;
– 34.35.00_Progetti-Perizie.

Non avendo la possibilità di fare ricerche mirate, un operatore è stato impegnato in maniera esclusiva allo spoglio dell'intero archivio informatico, verificando ogni documento singolarmente. Alla parte digitalizzata corrispondeva, talvolta, una parte di documentazione non scansionata, raccolta in faldoni cartacei. Questi allegati sono stati a loro volta digitalizzati in modo da acquisire e ricreare integralmente la documentazione originale. Sia all'archivio cartaceo, sia ai documenti scansionati nel sistema informatico di protocollo corrispondevano degli allegati formati da diverse tipologie di documentazione: disegni, rilievi e planimetrie conservati nell'archivio grafico; fotografie custodite nell'archivio fotografico; dati digitalizzati su supporto digitale (CD/DVD). A causa delle restrizioni dovute alla pandemia e della mole di materiale presente, in parte ancora non catalogato, si è stati costretti a dare priorità all'acquisizione della documentazione presente nell'archivio cartaceo e a quella digitalizzata, rimandando a una fase successiva la raccolta della documentazione grafica e fotografica conservata separatamente.

A latere del progetto, la SABAP Pisa e Livorno ha proceduto a scansionare planimetrie, sezioni, prospetti e disegni relativi a interventi, eseguiti dal

1929 al 2005, pertinenti a 12 comuni della provincia di Pisa. L'acquisizione delle tavole di piccolo formato è stata effettuata tramite scansione, mentre le tavole di grande formato o in precario stato di conservazione sono state acquisite tramite fotografie digitali zenitali successivamente processate mediante fotoraddrizzamento, eliminazione del disturbo e correzione della distorsione ottica. Per quanto riguarda l'archivio CD, sono stati acquisiti 646 CD, di cui 97 allegati dell'archivio cartaceo (anni 2002-2006) e 549 allegati di documenti protocollati in EsPI (2007-giugno 2016). Infine, ulteriore documentazione è stata digitalizzata presso le sedi della SABAP di Pisa. Si è trattato di documentazione cartacea, in parte conservata presso la già Soprintendenza ai Monumenti e Gallerie di Pisa e riguardante interventi archeologici o ritrovamenti sporadici effettuati tra il 1913 e il 1998, in parte non protocollata e conservata presso sedi distaccate della Soprintendenza, e di dati già digitalizzati su supporto CD.

3.1 *Acquisizione e post-produzione*

La digitalizzazione dei documenti cartacei è avvenuta mediante device mobili con fotocamera da 12 megapixel e HDR smart. Le immagini sono state acquisite in formato .jpeg a 300 dpi. Successivamente, il materiale fotografico raccolto è stato organizzato in un archivio digitale costituito da cartelle e sottocartelle che rispecchiasse fedelmente la struttura di quello fisico, con file .txt a corredo per segnalare la presenza di eventuali singolarità riscontrate in fase di acquisizione dei dati.

Tutti i documenti acquisiti sono stati processati eseguendo una serie di interventi di correzione (ritaglio, fotoraddrizzamento, cancellazione di eventuali disturbi) laddove necessario. Sono state stilate linee-guida destinate agli operatori e ai futuri fruitori in modo che la fase di correzione non andasse a incidere sulla preservazione della struttura dell'archivio fisico. Ogni documento è stato ricostruito creando il relativo file .PDF nominato con un numero progressivo. Tutti questi interventi sono stati effettuati attraverso l'uso del software GIMP-GNU Image Manipulation Program (https://www.gimp.org/). Avendo lavorato in maniera condivisa tramite GoogleDrive, per ogni faldone è stato creato un foglio di calcolo .gsheet (facilmente esportabile in formati aperti come .csv o proprietari come .xlsx) in cui sono stati inseriti tutti i dati riferibili al singolo documento: numero del faldone, denominazione della cartella e sottocartella in cui è conservato, denominazione della cartella contenente i file .PDF creati, numero del documento, posizione di archivio, numero di protocollo, anno, oggetto del documento, numero di pagine ed eventuali annotazioni.

Per questa attività, sono stati attivati dei tirocini che hanno visto la partecipazione degli studenti e delle studentesse dei corsi di laurea triennale, magistrale in Scienze dei Beni Culturali e Archeologia e della Scuola di Specializzazione in Beni Archeologici del Dipartimento di Civiltà e Forme del Sapere dell'Università di Pisa. Tale attività didattica ha avuto molteplici finalità:

– far comprendere ai e alle tirocinanti il lavoro svolto quotidianamente dalle soprintendenze nella gestione delle pratiche in entrata e in uscita;
– offrire agli studenti e alle studentesse competenze informatiche sull'utilizzo di programmi open source di editing di immagini e sistemi di archiviazione e condivisione dati;
– avere una documentazione organizzata pronta per essere analizzata nella successiva fase di popolamento.

L'intera documentazione acquisita e post-processata è stata riversata nel server di progetto mantenendo la suddivisione presente nell'Archivio originale in modo da fornire alle SABAP coinvolte un archivio digitalizzato organizzato secondo l'assetto di quello fisico.

4. Gestione e concettualizzazione del dato archeologico: il back end MAGOH

Per la gestione complessiva dei dati archeologici si è deciso di reingegnerizzare il precedente sistema MAPPA, basato su un database MS Access® accessibile solo su un server locale e di migrarlo su una soluzione web-based open source. L'applicativo di back end MAGOH è pensato per essere utilizzato via web e consentire operazioni di data entry decentrato con utenti diversificati in base ai criteri di accesso definiti su ruoli e base geografica. È possibile, ad esempio, definire un operatore o un'operatrice esterna che inserisca i dati relativi a un intervento archeologico solo su uno specifico territorio comunale e che abbia privilegi di scrittura e modifica solo sugli interventi da lui/lei creati. Tutte le operazioni di eliminazione, infine, sono settate come soft-delete, ovvero i dati cancellati vengono resi non visibili pur rimanendo sulla piattaforma fino a un'eventuale cancellazione definitiva ad opera solo degli amministratori di sistema (hard delete). L'applicativo è stato realizzato con il framework open source Bootstrap (https://getbootstrap.com/), che comprende una serie di tool rilasciati con licenza libera MIT. Esso è alimentato dai dati immagazzinati all'interno di un geodatabase PostgreSQL (versione 9.5.19) (https://www.postgresql.org/) con estensione PostGIS 2.2 (http://www.postgis.net/).

L'applicativo si appoggia a un'istanza di GeoServer (2.18.1) (https://geoserver.org/) opportunamente configurata, utile non solo per pubblicare i dataset MAGOH attraverso i principali geoservizi, ma anche per centralizzare la gestione di risorse cartografiche erogate da altri enti e ritenute di interesse per il progetto. Il geoserver di produzione è organizzato in due workspace: "cartografia_base" e "dati_magoh". Il primo contiene vari store, soprattutto di tipo WMS, che raccolgono le principali cartografie ufficiali disponibili per l'area di progetto (CTR, ortofoto, catasto, VincoliinRete, GEOscopio Regione Toscana); il secondo, invece, eroga i dati spaziali provenienti dal geodatabase MAGOH (Interventi, Ritrovamenti - III livelli ed Evidenze Archeologiche

- IV livelli) sotto forma di servizi WMS e WFS. Infine, attraverso il geoserver è possibile operare su applicativo anche attraverso il software open source QGIS. Questa completa integrazione tra applicativo web e QGIS permette una maggiore fluidità nella georeferenziazione di cartografie o piante di scavo e nella vettorializzazione di dati graficamente complessi, permettendo, altresì, la compilazione di alcuni campi della tabella attributi. I dati così creati vengono visualizzati in tempo reale sull'applicativo web dove è possibile raffinare e completare le informazioni inserite, compilando i campi tralasciati e allegando la documentazione relativa.

Questa modalità di interazione è destinata solo a un'utenza con privilegi di accesso avanzati. Diversamente, l'operatore o operatrice può creare un proprio progetto QGIS esterno, dedicato, e successivamente caricare le geometrie attraverso un tool di upload che consente di connettere la singola feature geometrica alla scheda dell'intervento e/o all'evidenza archeologica precedentemente inserite sul portale web. Il modello concettuale alla base dell'immissione dei dati non è stato modificato rispetto a MAPPA e continua a basarsi su tre gradi informativi primari:

– Scheda di Intervento;
– Scheda di Ritrovamento;
– Scheda di Evidenza archeologica.

A questi si aggiungono dei livelli informativi tematici, come le Tracce da Aerofotointerpretazione, e di dettaglio come le Schede US, le Schede di Attività, Fase e Periodo e le Schede di Sepoltura (Anichini *et al.* 2012, 2013; Gattiglia, Roberto 2020).

I dati estrapolati dalla documentazione acquisita sono stati organizzati secondo quattro diverse sezioni:

– dati geo-spaziali, ovvero l'insieme delle geometrie legate a un determinato intervento, composte da feature poligonali o puntuali;
– componente alfanumerica associata alle entità;
– metadati semantici;
– documenti digitali, che comprendono tutti i tipi di documentazione collegata a ogni singolo intervento archeologico.

La Scheda di Intervento (Fig. 2) costituisce la scheda anagrafica all'interno della quale sono inseriti dati geografici, amministrativi, scientifico-metodologici, cartografici e redazionali. Oltre alle entità in essa contenute, a questa scheda è associata una serie di tabelle per la definizione delle seguenti informazioni (Fig. 3):

– localizzazione;
– descrizione;
– unità stratigrafiche;

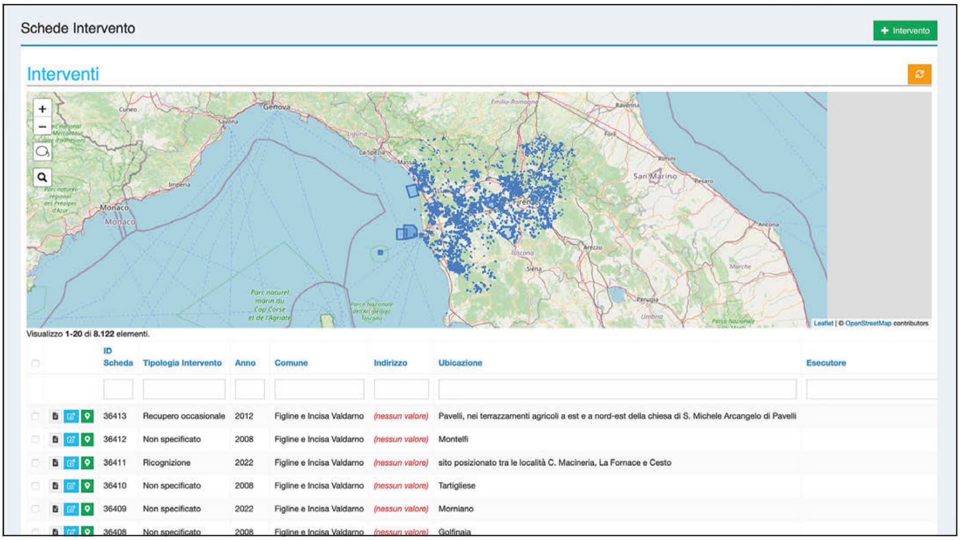


Fig. 2 – Back end MAGOH. In alto la mappa con le geometrie di tutti gli interventi inseriti; in basso i campi di ricerca e la lista degli interventi partendo dall'inserimento più recente (dicembre 2022).

– periodo/fase/attività;
– collocazioni, cioè la conservazione fisica di tutto l'apparato materiale e documentale legato all'intervento;
– bibliografia;
– documenti, cioè tutti gli allegati che contengono dati testuali, cartografici/planimetrici e fotografici legati a quell'intervento e tutti caricati nell'applicativo back end;
– tabella di associazione tra interventi e utenti, in modo da poter consentire agli operatori esterni di poter operare con privilegi di scrittura e modifica solo per il territorio su cui sono stati autorizzati a intervenire.

Le geometrie associate alla scheda sono di tipo poligonale anche nei casi in cui la localizzazione non sia georeferibile con precisione; in ogni caso, il grado di precisione della localizzazione è trattato come un attributo (preciso/non preciso/non localizzabile).

La Scheda di Ritrovamento (Fig. 4) è collegata alla Scheda di Intervento con un rapporto 1:M, ossia a ciascun intervento possono essere collegate molteplici schede di Ritrovamento. In questa scheda, detta anche di III livello, si fornisce una sintesi interpretata della tipologia del ritrovamento archeologico ed è così definita perché è basata su tre livelli che specificano progressivamente il dato e sono legati tra loro mediante un *thesaurus* gerarchico (Anichini *et al.* 2012, 35-39, 46). Il I livello è il grado più generico e fornisce

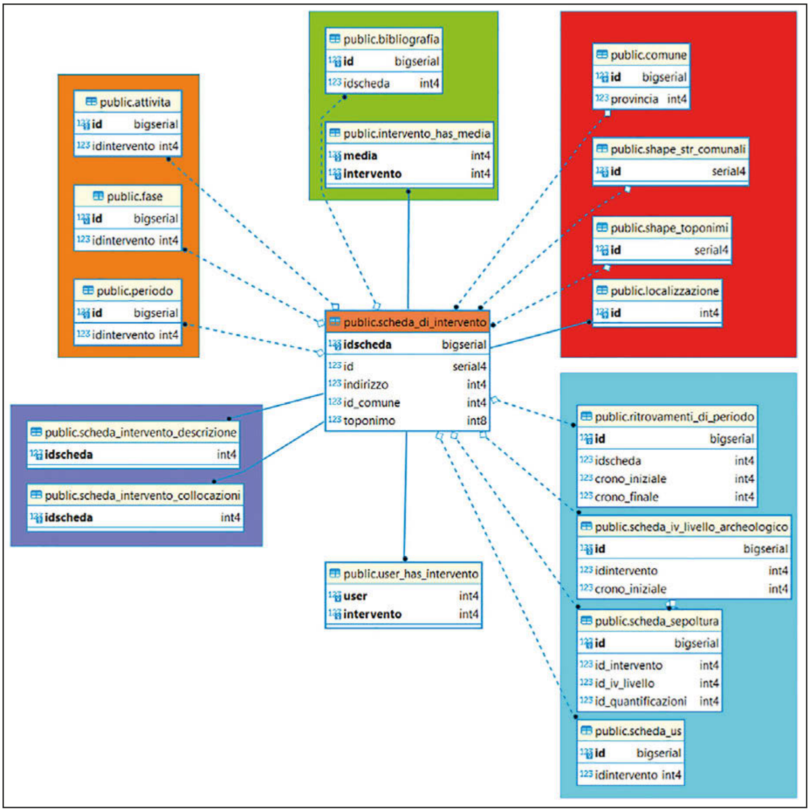


Fig. 3 – Diagramma E-R: Scheda di Intervento e tabelle collegate, per le quali sono indicate solo le chiavi primarie o esterne, da Anichini *et al.* 2021b, fig. 2.

un'interpretazione molto ampia (ad es. Area funeraria), che viene precisata con il II livello (ad es. Tomba/e) e ulteriormente definita con il III livello che rimanda a una specifica destinazione d'uso (ad es. ad incinerazione). Insieme determinano la denominazione del Ritrovamento. La rappresentazione del dato è puntuale e il posizionamento all'interno del poligono di intervento è basato sulle informazioni spaziali possedute: se è possibile definirne l'esatta ubicazione, il posizionamento del grafo è nel luogo reale; se la posizione è approssimativa o l'area del ritrovamento corrisponde all'intera area dell'intervento, l'ubicazione del grafo coincide con il centroide del poligono corrispondente all'area di intervento. Il grafo puntuale non indica una maggiore precisione, al contrario, identifica la semplice presenza di un determinato tipo di ritrovamento, la cui precisione di localizzazione è eventualmente attestata dalla vettorializzazione dei sottostanti IV livelli.

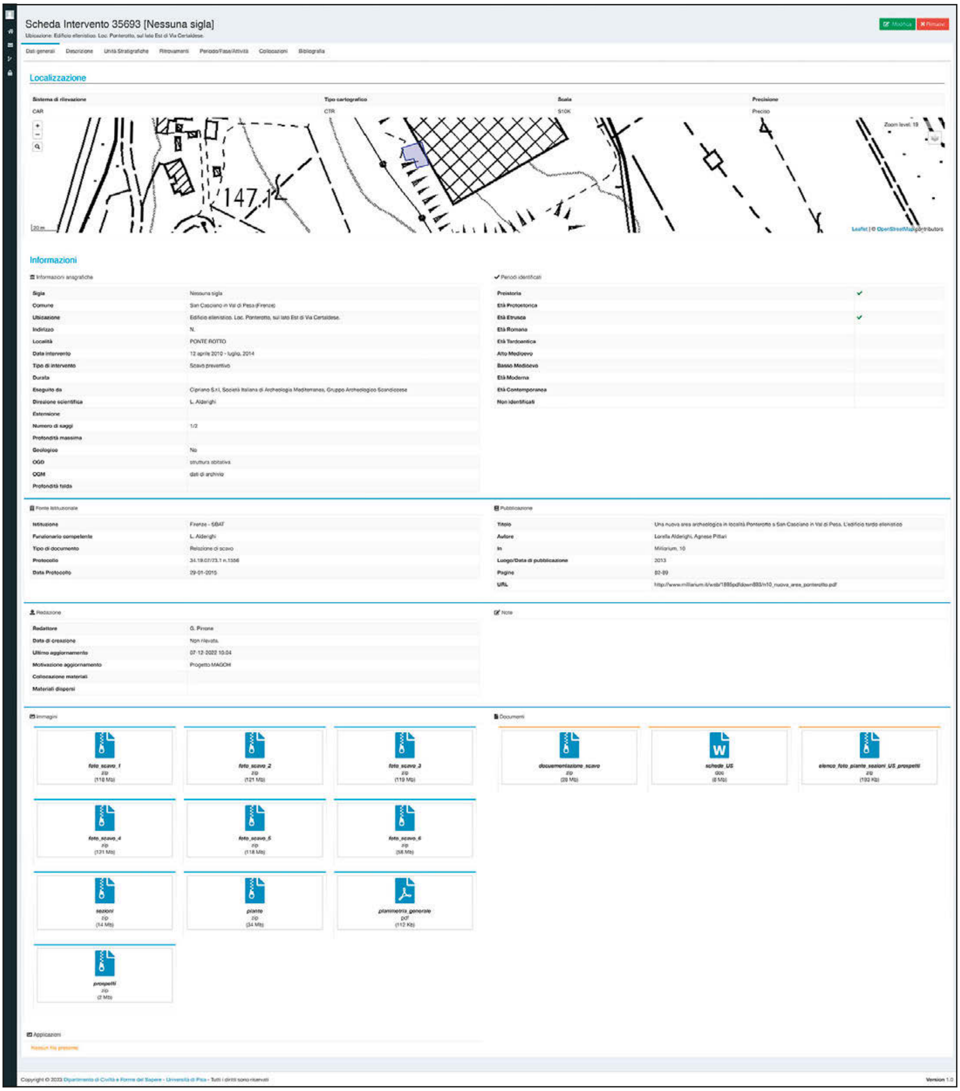


Fig. 4 – Back end MAGOH: Scheda di Intervento.

L'utilizzo del grafo poligonale è ripreso con la scheda di Evidenza archeologica, il IV livello informativo del dato, che indica la tipologia dei principali resti archeologici emersi (qui intesi ad es. come strutture murarie, pavimentazioni, fosse di sepoltura, etc. non come singole US, per le quali è prevista una schedatura apposita) (Fig. 5).

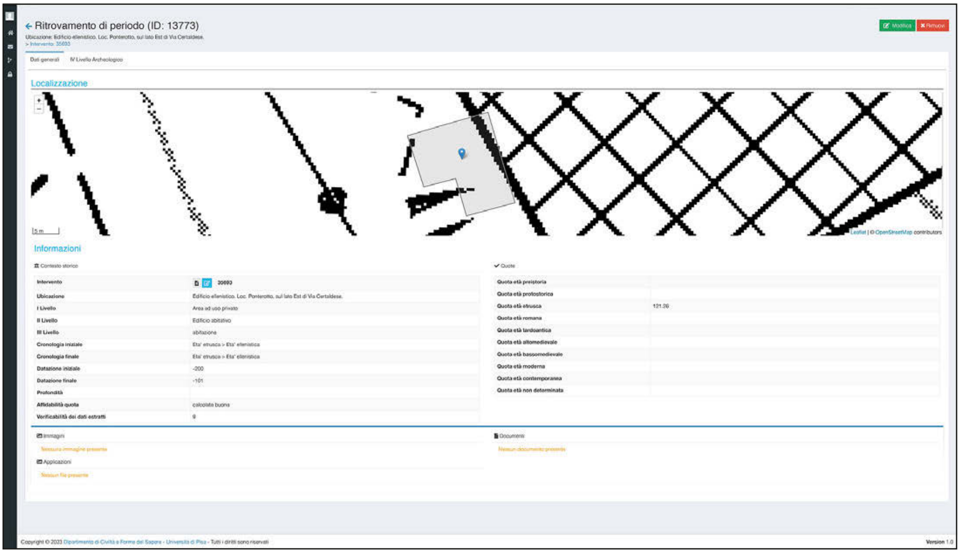


Fig. 5 – Back end MAGOH: Scheda di Ritrovamento.

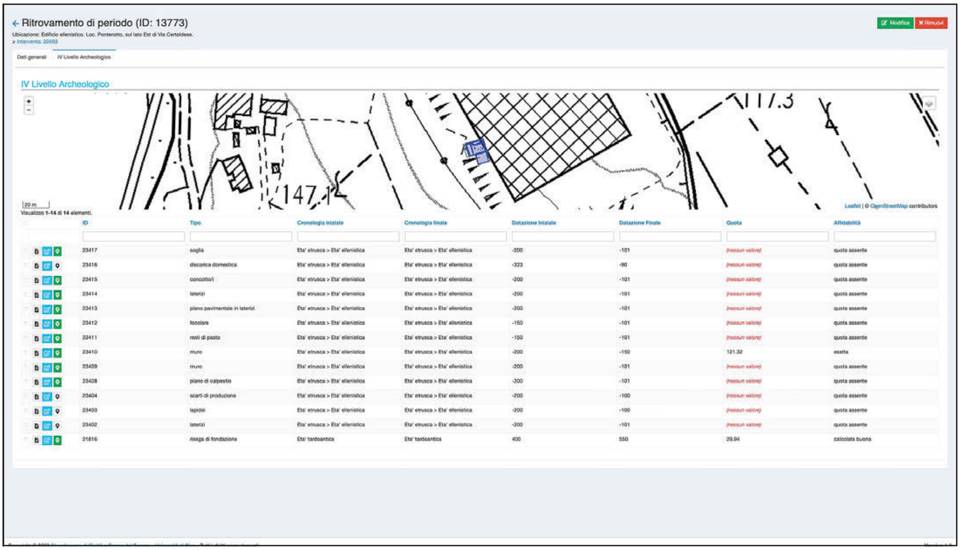
4.1 *Gestione e formalizzazione delle cronologie*

La formalizzazione del dato cronologico in archeologia rappresenta un elemento critico. Risulta complesso gestire datazioni spesso sfumate e incerte, come ad esempio la prima metà di un secolo, in termini numerici assoluti. Per questo, è stato proposto di gestire l'indeterminatezza delle cronologie numeriche attraverso la fuzzy logic (Hermon, Niccolucci 2017) o definendo dei *thesauri* cronologici di riferimento (Niccolucci, Hermon 2016) che risultano, però, spesso applicabili solo a realtà geografiche ben definite e non generalizzabili. Questo secondo metodo era alla base della gestione delle cronologie all'interno del progetto MAPPA (Dubbini, Gattiglia 2016). L'estremo dettaglio geografico, legato alla sola realtà pisana, poneva, però, delle difficoltà nell'utilizzare lo stesso *thesaurus* cronologico, composto da cronologie testuali, alcune con riferimenti etnici e/o a culture, associate a precisi range cronologici numerici, per un'area corrispondente a quasi tutta la Toscana settentrionale.

Pertanto, è stata necessaria un'approfondita riflessione sulla concettualizzazione e mappatura delle cronologie all'interno di MAGOH, che, pur mantenendo lo stesso approccio, ha fatto riferimento a cronontologie sviluppate da gazetteer internazionali. Nello specifico, la definizione dei singoli range cronologici (Anichini *et al.* 2021b) è stata costruita sulla base dei *thesauri* cronologici di PeriodO (https://perio.do/en/), curato dalle Università del Texas e del Nord Carolina, e iDAI.chronontology (https://chronontology.dainst.org/), curato dall'Istituto Archeologico Germanico di Berlino, e fatta confluire nei campi testuali "Cronologia iniziale", "Cronologia finale", collegati ai corrispondenti campi numerici "Datazione iniziale" e "Datazione finale" delle schede di Ritrovamento e di Evidenza Archeologica. Selezionando un determinato valore dal *thesaurus* a tendina presente nei primi due campi, si vanno ad associare dei valori numerici, basati sulle cronontologie di riferimento, che compilano automaticamente i campi "Datazione", definendo l'estensione massima dell'arco temporale. In possesso di dati di maggior dettaglio, è possibile raffinare il dato cronologico, purché rispetti l'arco temporale già fissato; diversamente, il sistema produce un alert non vincolante. In tal modo, il lavoro di data entry risulta più veloce e controllato, riducendo i margini di errore, migliorando l'interoperabilità, la condivisione, nonché la comprensione del dato cronologico che, grazie alla presenza della codifica numerica, potrà essere poi riclassificato dagli applicativi che ricevono le informazioni. Tutti i *thesauri* e le codifiche dei range cronologici numerici sono pubblicati all'interno dell'archivio open data di MAGOH e resi disponibili per il loro riuso.

5. Il popolamento

La fase di popolamento è risultata più lunga di quanto preventivato e ha portato al reclutamento progressivo di ulteriori cinque unità di personale a tempo pieno, che sono andate a integrarsi con i ricercatori del MAPPALab, già impegnati in attività di ricerca su alcuni comuni interessati dal progetto,



ID	Tipo	Cronologia iniziale	Cronologia finale	Datazione Iniziale	Datazione Finale	Quota	Affidabilità
23417	soglia	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
23416	discarica domestica	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-323	-90	(nessun valore)	quota assente
23415	concotto/i	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
23414	laterizi	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
23413	piano pavimentale in laterizi	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
23412	focolare	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-150	-101	(nessun valore)	quota assente
23411	resti di pasto	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-150	-101	(nessun valore)	quota assente
23410	muro	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-150	121.32	esatta
23409	muro	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
23408	piano di calpestio	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
23404	scarti di produzione	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-100	(nessun valore)	quota assente
23403	lapidei	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-100	(nessun valore)	quota assente
23402	laterizi	Eta' etrusca > Eta' ellenistica	Eta' etrusca > Eta' ellenistica	-200	-101	(nessun valore)	quota assente
21816	risega di fondazione	Eta' tardoantica	Eta' tardoantica	400	550	29.94	calcolata buona

Fig. 6 – Back end MAGOH: lista di schede di Evidenze Archeologiche; in alto, rappresentazione.

e con alcuni archeologi liberi professionisti che hanno testato l'efficienza e l'efficacia dell'applicativo rispetto alle esigenze di tutela.

La mole di dati processata è stata considerevole. Si tratta di oltre un terabyte di dati: 15.000 documenti e quasi 700 CD contenenti relazioni di scavo, schede di US, disegni, foto, piante, a cui si aggiungono lavori di sintesi territoriali, censimenti di evidenze archeologiche, aggiornamenti recenti di alcune aree di ricerca. Il materiale edito non è stato ricognito in forma esaustiva, ma utilizzato come fonte di integrazione delle informazioni solo in caso di interventi particolarmente articolati e complessi o laddove sintesi note non trovavano riscontri nella documentazione presente in archivio. Complessivamente sono stati lavorati integralmente i dati di 87 comuni, per un totale di quasi 8000 interventi archeologici inseriti, a cui si associano 11.850 schede di Ritrovamento e oltre 20.000 schede di Evidenze Archeologiche.

6. Il front end

Per la divulgazione e consultazione dei dati è stato realizzato un front end user-friendly in cui confluiscono i dati registrati nell'applicativo, organizzati e settati in modo che siano visibili, consultabili e comprensibili dall'ampia platea che utilizza la rete (https://magoh.cfs.unipi.it). Il front end unisce aspetti geografici, tipici di un webGIS, con la consultazione completa della base di dati resa possibile dall'indicizzazione di tutti i campi. Tale indicizzazione, ottenuta tramite Apache Solr (https://solr.apache.org/), permette la ricerca full text, la hit highlighting, la faceted search e il raggruppamento dinamico,

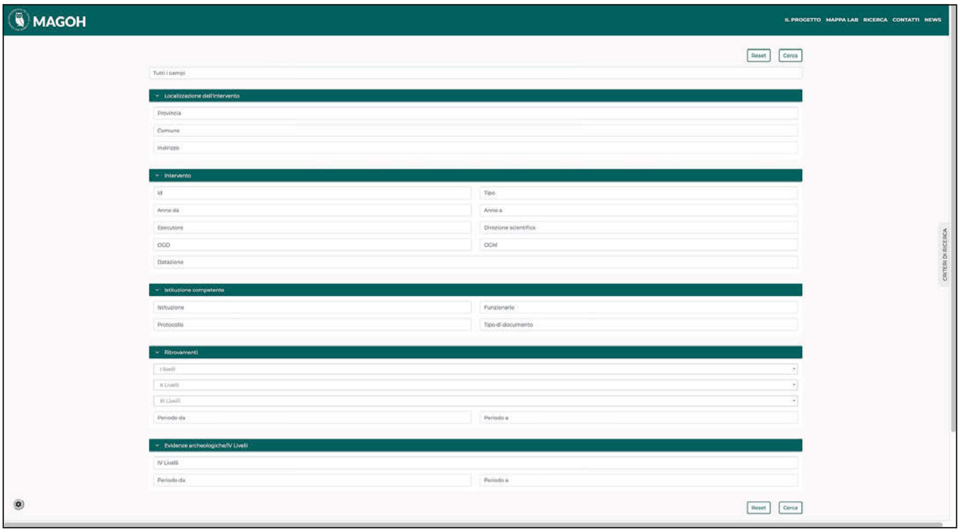


Fig. 7 – Front end MAGOH: campi di ricerca (dicembre 2022).

consentendo la ricerca integrale della base di dati e l'utilizzo di filtri a faccetta che rendono possibile sia il conteggio delle voci, sia il raffinamento progressivo della ricerca (Fig. 6). Questa diventa dinamica attraverso il tab Criteri di Ricerca che permette di mantenere o eliminare a scelta i campi selezionati, per modificare i risultati ottenuti (Fig. 7). È possibile filtrare i risultati sulla base dell'anno di esecuzione degli interventi, attraverso una barra cronologica interattiva, e selezionare tutti i ritrovamenti archeologici mediante ricerche numeriche che definiscano inizio e fine di range cronologici a scelta.

La lista dei risultati di ricerca consente di visualizzare alcune informazioni chiave dell'intervento archeologico quali localizzazione, anno, tipologia (ad es. scavo programmato, assistenza, recupero occasionale, etc.), tipo di rinvenimento (che utilizza il thesaurus ICCD del campo OGD, ad es. area priva di tracce archeologiche, insediamento, infrastruttura idrica, etc.) e periodo identificato (ad es. preistoria, età etrusca, età moderna, etc.) (Fig. 8). L'esperienza per l'utente è completa: gli interventi archeologici sono visibili nella loro interezza, associando il dato testuale a quello grafico (Fig. 9). È, inoltre, possibile condividere i permalink di ogni scheda, eseguirne la stampa in formato .PDF o inviarla direttamente via e-mail. Mediante registrazione (non obbligatoria), l'utente ha accesso ad alcune funzioni avanzate, quali, ad esempio, la possibilità di creare collezioni personalizzate di interventi per determinati ambiti territoriali o tematici e la condivisione delle relative schede tra più utenti o gruppi di utenti.

I dati prodotti dal progetto, oltre a essere liberamente accessibili, saranno

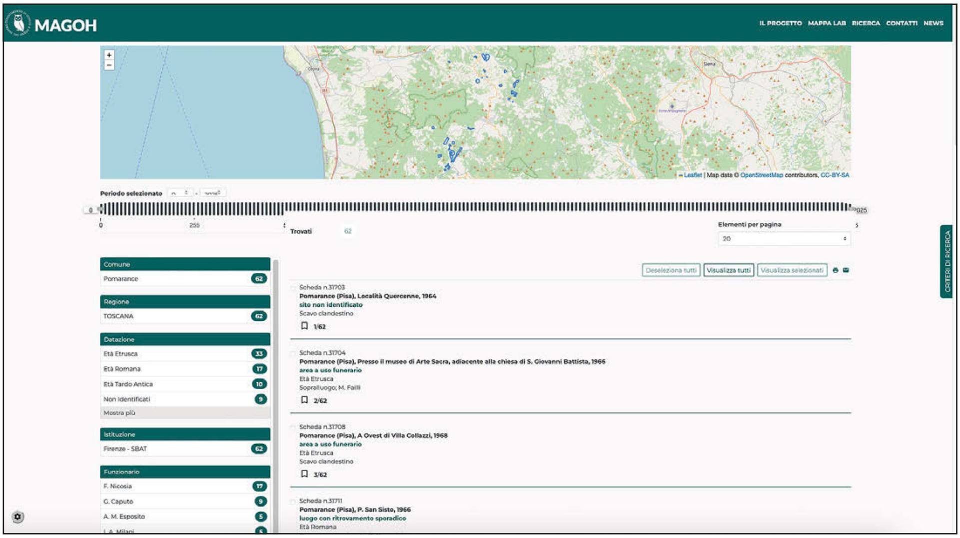


Fig. 8 – Front end MAGOH: lista dei risultati. In alto, la mappa con il posizionamento di tutti i risultati; sotto, il filtro cronologico a faccetta; a sinistra, i filtri connessi ai diversi campi di ricerca (dicembre 2022).

disponibili come open data, sia scaricando i dati geometrici e testuali ottenuti dalle ricerche effettuate, sia come dataset nella sua interezza disponibile in un archivio dedicato sul MOD (MAPPA Open Data) ospitato all'interno della Digital Library del Dipartimento di Civiltà e Forme del Sapere dell'Università di Pisa (https://digitallib.unipi.it/). Dove possibile, la documentazione di archivio digitalizzata è stata resa disponibile in maniera aperta con licenza CC-BY-SA e CC-BY-SA-NC per le immagini; viceversa sarà possibile contattare direttamente dall'applicativo il responsabile dell'archivio delle SABAP per ottenerne una copia digitale.

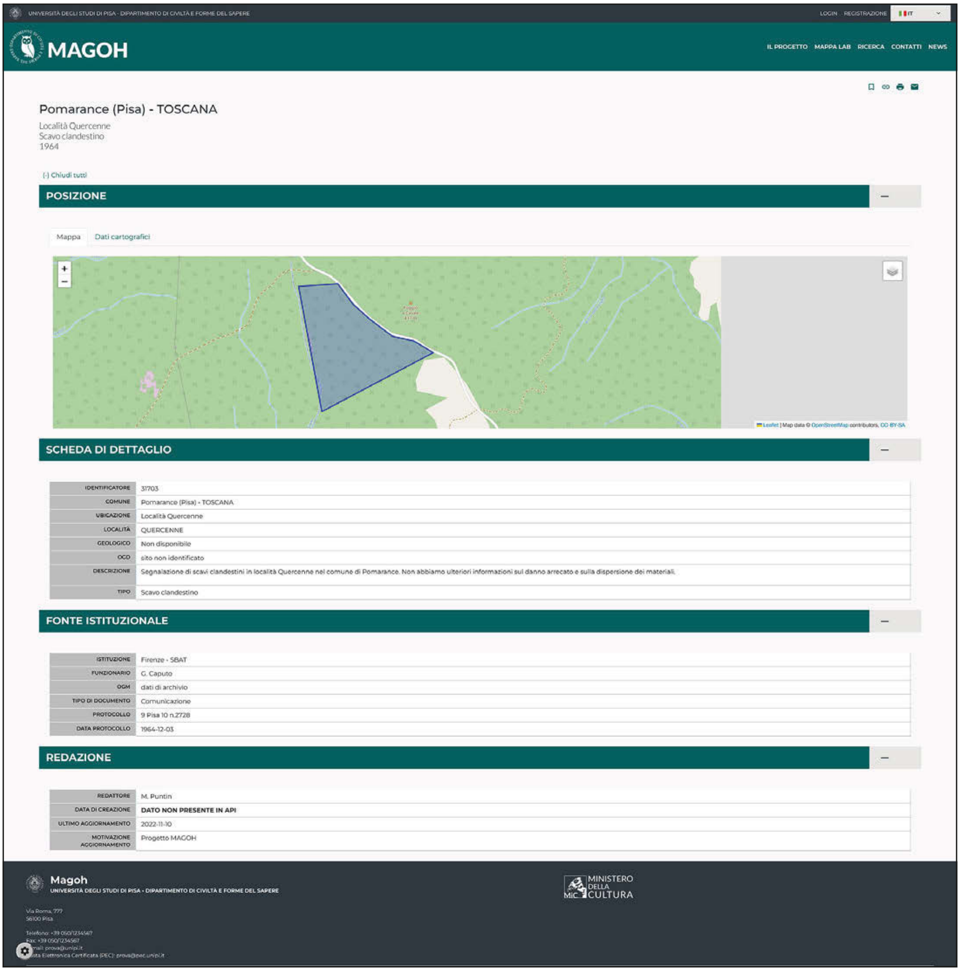


Fig. 9 – Front end MAGOH: Scheda di Intervento. In alto, i dati di localizzazione e il posizionamento su mappa; sotto, le varie schede catalografiche connesse (dicembre 2022).

7. MAGOH e GNA: due incubatori interoperabili

Sin dalla fase progettuale, il team di progetto si è confrontato con l'Istituto Centrale per l'Archeologia (ICA) che da diversi anni sta lavorando alla riorganizzazione di tutta la documentazione inerente all'archeologia preventiva che arriva alle SABAP (Calandra *et al.* 2021). Ad aprile 2022, ICA ha rilasciato le prime linee guida volte a sistematizzare la redazione e la consegna delle VPIA per farle confluire nel Geoportale Nazionale Archelogia (GNA, http://www.ic_archeo.beniculturali.it/it/222/il-geoportale-nazionale-per-l-archeologia). Attualmente, la normativa prevede la compilazione di un template QGIS, contenente tabelle attributi con campi obbligatori e vocabolari chiusi, in cui confluiscono le informazioni del progetto, i dati sul censimento bibliografico delle evidenze archeologiche e quelli raccolti tramite ricognizione e fotointerpretazione. Per rendere interoperabili i due sistemi e condividere i dati presenti nell'applicativo MAGOH con lo GNA, sono stati mappati e resi obbligatori tutti i campi della scheda di Intervento obbligatori nella scheda MOSI del GNA, aggiungendo anche i campi, originariamente non previsti, OGD e OGM rispettivamenti riferiti alla denominazione (D) e alla modalità di individuazione (M) del bene culturale (OG). Quindi, sono state sviluppate delle API dedicate che permettono ai dati raccolti nell'applicativo MAGOH di confluire nel portale GNA aggiornandolo attraverso un flusso continuo di informazioni testuali e vettoriali in formato .geojson, anche se alla base dei due sistemi c'è una metodologia e una formalizzazione dei dati differente.

8. Discussione

L'obiettivo principale del Progetto MAGOH è stato quello di creare una piattaforma integrata in grado di gestire la mole di dati archeologi provenienti dalle quotidiane attività di tutela del territorio, facendo confluire in un unico contenitore varie tipologie e formati di documentazione. Da questo punto di vista, si inserisce nel solco di progetti come MAPPA, da cui trae origine, RAPTOR (Ricerca Archivi e Pratiche per la Tutela Operativa Regionale) (Frassine, Naponiello 2012; Frassine *et al.* 2016, 2021) e SITAR (Sistema Informativo Territoriale Archeologico di Roma) (Serlorenzi 2018; Serlorenzi *et al.* 2012; 2021), con i suoi progetti satellite sulle città di Verona (SITAVR; Basso *et al.* 2015) e Siena (SITAS; https://sitas.archeositarproject.it/ui/), ma se ne differenzia per una più accentuata simmetria tra le esigenze di tutela, per le quali nasce, e di ricerca, per le quali si rivela un potente strumento, ed è pensato per dialogare con lo GNA come il recente ArcheoDB dell'Emilia Romagna, sviluppato a partire dal 2019 e attualmente utilizzato in tutta la regione come strumento per la raccolta dei dati archeologici (https://www.patrimonioculturale-er.it/webgis/).

Anche in campo internazionale sono state create piattaforme on line per l'organizzazione, la gestione e la fruibilità dei dati archeologi testuali e cartografici. Alcuni esempi sono: 1) il MayaArch3D Project (https://mayaarch3d.org/en/), non più attivo, promosso dal German Archaeological Institute (DAI) e dal GIScience Research Group dell'Università di Heidelberg, che aveva come obiettivo quello di creare un ambiente di ricerca virtuale sul sito di Copan in Honduras, riunendo in un unico contenitore la documentazione testuale (compresa quella d'archivio), grafica e cartografica, con particolare attenzione alle ricostruzioni e ai modelli 3D integrati all'interno del GIS; 2) la mappa interattiva per la consultazione dei dati legati al progetto "The Rural Settlement of Roman Britain: an online resource" (https://doi.org/10.5284/1030449), aggiornato al 2018, e che include anche la pubblicazione dei report di scavo dal 1990 al 2016; 3) il webGIS ideato dalla Dypilon Society sulla città di Atene, il Mapping Ancient Athens (https://mappingancientathens.org/en/home/), una piattaforma realizzata tra il 2018 e il 2021, dove sono stati analizzati, organizzati e resi fruibili dati testuali e grafici georeferenziati di 670 scavi condotti nella capitale greca degli ultimi 160 anni. In questi casi si tratta di progetti relativi a siti specifici, tematiche definite o a un ambito territoriale circoscritto.

Nel progetto MAGOH gli obiettivi sono stati ampliati andando, innanzi tutto, a intervenire su una vasta scala territoriale, eterogenea per caratteristiche geografiche e insediative; inoltre è stato innalzato il livello di fruibilità dei dati, rendendo disponibili tutte le feature vettoriali realizzate e accessibile la documentazione di archivio testuale e grafica. Tale approccio ha permesso di aumentare il potenziale scientifico messo a disposizione dei diversi operatori, pubblici e privati, che lavorano quotidianamente con i dati territoriali storico-archeologici, culturali, paesaggistici.

Alcuni punti chiave del progetto sono indicati di seguito.

La conservazione e la preservazione del dato sono state perseguite attraverso la completa digitalizzazione dell'archivio cartaceo e l'acquisizione della documentazione già digitalizzata. Il dato cartaceo pone problemi in termini di conservazione, spazio e fruizione; problemi resi ancor più evidenti durante la pandemia che ha mostrato l'importanza di avere dati aperti e condivisi all'interno della comunità archeologica. Allo stesso tempo, anche il dato conservato su supporti digitali, come HardDisk e CDRom/DVD, richiede che ne sia garantita una preservazione permanente, in quanto soggetto a processi di deterioramento e obsolescenza del supporto. La scelta di optare per una policy open data, secondo i principi FAIR e nel solco del progetto MAPPA, va proprio incontro a queste necessità di accessibilità e preservazione a lungo termine. L'openess complessiva del progetto è, inoltre, rafforzata dalla completa migrazione open source dell'originario sistema MAPPA ottenuta con la reingegnerizzazione dell'applicativo web-based.

L'applicativo è stato realizzato e studiato per ottemperare alle esigenze dei funzionari, che sono state preventivamente analizzate attraverso un questionario dedicato e una serie di incontri con il personale delle SABAP coinvolte. Questi hanno sia evidenziato le problematiche relative ai processi di gestione dei dati, sia offerto proposte, poi recepite dal team di ricerca (Anichini *et al.* 2021a), sia fatto emergere come la disponibilità dei documenti digitalizzati e aperti, nel rispetto dei diritti di privacy e proprietà intellettuale previste dalla legge, si ponga come risultante di fondamentale importanza per snellire le procedure quotidiane di tutela e valorizzazione del patrimonio archeologico.

Lo strumento realizzato consente un immediato accesso a tutte le tipologie di documentazione legate a un determinato intervento archeologico, evitandone la ricerca nei vari sistemi di archiviazione stratificatisi negli anni, e, al contempo, permette una visione del dato a livello spaziale e territoriale, facilitando il lavoro di tutela connesso all'emissione di pareri, alla partecipazione a conferenze di servizi, alla pianificazione territoriale, all'emanazione dei piani strutturali comunali, etc. Le ripercussioni dell'adozione di un sistema di questo tipo nel campo della tutela sono state ampiamente verificate su scala urbana mediante l'utilizzo del sistema MAPPA; l'ampliamento della competenza territoriale, la metodologia di popolamento e la modalità di inserimento dei dati sono stati subito percepiti come un netto miglioramento nella conoscenza del territorio coinvolto dal progetto.

Le sfide affrontate, considerando i ritardi dovuti alla pandemia, sono state notevoli. La mole di dati acquisita e processata è risultata copiosa, facendo emergere un evidente errore di stima nel momento di redazione del progetto che ha sottovalutato la quantità di lavoro necessario, al punto da rendere imprescindibile il reclutamento di ulteriori operatori rispetto ai tre assegnisti originariamente previsti. Questo aspetto ha fatto emergere con chiarezza la questione della sostenibilità futura del progetto. Come già per MAPPAgis, il portale MAGOH sarà gestito sui server dell'Università di Pisa, che ne curerà la manutenzione. Un tale strumento, però, per essere pienamente fruibile, ha bisogno di avere una base dati sempre aggiornata. Per raggiungere un obiettivo così ambizioso, si è pensato di adottare un aggiornamento decentrato e diffuso nel quale, attraverso la gestione di diversi privilegi di accesso, sia i funzionari delle SABAP, sia gli operatori e le operatrici dell'archeologia professionale potranno curare l'inserimento dei dati, che saranno pubblicati dopo un processo di validazione da parte dei funzionari competenti. Un processo di verifica continua permetterà di valutare la procedura e approntare gli eventuali correttivi tecnici e/o metodologici.

MAGOH mette a disposizione di chiunque, liberi/e professionisti/e, ricercatori/trici, cittadini/e, dati che in precedenza dovevano essere ricercati in archivio con molto dispendio in termini di tempi e costi. Inoltre, la mole di dati disponibili su un ambito territoriale coincidente con gran parte della Toscana settentrionale si configura come un esempio di big data archeologici e potrà consentire analisi quantitative mai tentate prima in quest'area geografica, che potranno aprire campi di ricerca finora inesplorati.

Ulteriori azioni di implementazione dei dati d'archivio, relativi ad altri territori comunali, sono già state messe in atto dal MAPPALab, con l'obiettivo di estendere il sistema e poter così giungere a una modalità comune di gestione, valorizzazione e condivisione dei dati su scala sub-regionale e regionale, fornendo, allo stesso tempo, nuovi dati per l'implementazione del GNA. In ultimo, si prevede di investire progressivamente nell'integrazione dei dati presenti con l'inserimento delle informazioni provenienti dalla revisione di tutto il materiale edito e il costante aggiornamento dei nuovi dati prodotti.

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BIBLIOGRAFIA

Anichini F., Dubbini N., Fabiani F., Gattiglia G., Gualandi M.L. 2013, *MAPPA. Metodologie Applicate alla Predittività del Potenziale Archeologico*, 2, Roma, Nuova Cultura.

Anichini F., Fabiani F., Gattiglia G., Gualandi M.L. 2012, *MAPPA. Metodologie Applicate alla Predittività del Potenziale Archeologico*, 1, Roma, Nuova Cultura.

Anichini F., Gattiglia G., Montalbano R., Saponara A.R., Zanni S. 2021a, *Analisi delle procedure interne di gestione delle pratiche alle Soprintendenze Archeologia, Belle Arti e Paesaggio*, Report D1.1.

Anichini F., Gattiglia G., Montalbano R., Saponara A.R., Zanni S. 2021b, *Modello dati, applicativo web e servizi erogabili*, Report D1.2.

Anichini F., Gattiglia G., Montalbano R., Saponara A.R., Zanni S. 2021c, *Acquisizione dati archeologici dagli archivi delle SABAP-FI e PI-LI*, Report D2.1.

Arbeid B., Bueno M., Tarantini M. 2020, *Gli archivi della Soprintendenza archeologia della Toscana*, in Pessina, Tarantini 2020a, 73-103.

Basso P., Belussi A., Bruno B., Grossi P., Migliorini S. 2015, *Progetto SITAVR. Una carta archeologica per Verona*, in G. Leoni, M. Serlorenzi (eds.), *Il SITAR nella Rete della ricerca italiana. Verso la conoscenza archeologica condivisa. Atti del III Convegno (Roma 2013)*, «Archeologia e Calcolatori», Suppl. 7, 155-167 (http://www.archcalc.cnr.it/indice/Suppl_7/18_Bruno_et_al.pdf).

Calandra E., Boi V., Falcone A., Acconcia V., Di Giorgio S., Massara F., Ronzino P. 2021, *Policy and practice for digital archaeological archiving in Italy*, «Internet Archaeology», 58 (https://doi.org/10.11141/ia.58.27).

Conti P., Tarantini M. 2020, *L'archivio storico della Soprintendenza archeologia della Toscana*, in Pessina, Tarantini 2020a, 49-72.

Dubbini N., Gattiglia G. 2016, *Information and time in predictive modelling*, in *Proceedings of the 1st International Conference on Metrology for Archaeology (Benevento 2015)*, 373-377.

Frassine M., De Francesco S., Zambetti A. 2021, *RAPTOR reloaded. Un geodatabase gestionale per la tutela archeologica: nuovi aggiornamenti per un sistema aperto*, «Archeologia e Calcolatori», 32, 1, 307-324 (http://www.archcalc.cnr.it/indice/PDF32.1/17_Frassine_et_al.pdf).

Frassine M., Naponiello G. 2012, *RAPTOR: archeologia e tutela. Verso la pubblica amministrazione digitale*, «Archeologia e Calcolatori», 23, 81-99 (http://www.archcalc.cnr.it/indice/PDF23/05_Frassine_Naponiello.pdf).

Frassine M., Naponiello G., De Francesco S., Asta A. 2016, *RAPTOR 1.5. Aggiornamenti* *e sperimentazione*, in P. Basso, A. Caravale, P. Grossi (eds.), *ArcheoFOSS. Free, Libre and Open Source Software e Open Format nei processi di ricerca archeologica, Atti del IX Workshop (Verona 2014)*, «Archeologia e Calcolatori», Suppl. 8, 61-67 (http://www.archcalc.cnr.it/indice/Suppl_8/09_Frassine_et_al.pdf).

Gattiglia G. 2012, *GIS applications for the archaeological analysis of a medieval town: Pisa, Italy*, in F. Giligny , L. Costa , F. Djindjian , P. Ciezar , B. Desachy (eds.), *Actes des 2èmes Journées d'Informatique et Archéologie de Paris-JIAP 2010*, «Archeologia e Calcolatori», Suppl. 3, 124-140 (http://www.archcalc.cnr.it/indice/Suppl_3/09-gattiglia.pdf).

Gattiglia G., Roberto S. 2020, *Le necropoli urbane di Pisa tra tarda antichità e basso medioevo. Analisi preliminari*, «Studi Classici Orientali», 66, 329-346 (https://doi.org/10.12871/978883339362921).

Hermon S., Niccolucci F. 2017, *Formally defining the time-space-archaeological culture relation: Problems and prospects*, «Archeologia e Calcolatori», 28, 1, 93-108 (https://doi.org/10.19282/AC.28.1.2017.06).

Niccolucci F., Hermon S. 2016, *Representing gazetteers and period thesauri in four-dimensional space-time*, «International Journal on Digital Libraries», 17.1, 63-69.

Pessina A., Tarantini M. (eds.) 2020a, *Archivi dell'archeologia italiana. Atti della Giornata di Studi Archivi dell'archeologia italiana. Progetti, problemi, prospettive (Firenze 2016)*, Roma, Ministero per i Beni e le Attività culturali e per il Turismo. Direzione generale Archivi.

Pessina A., Tarantini M. 2020b, *Per gli archivi dell'archeologia italiana*, in Pessina, Tarantini 2020a, XV-XIX.

Serlorenzi M. 2018, *Accessibilità e diffusione del dato archeologico: l'esperienza del SITAR*, in M. Arizza, V. Boi, A. Caravale, A. Palombini, A. Piergrossi (eds.), *I dati archeologici. Accessibilità, proprietà, disseminazione (Roma 2017)*, «Archeologia e Calcolatori», 29, 31-40 (https://doi.org/10.19282/ac.29.2018.04).

Serlorenzi M., Cordone C., Lamonaca F., Picciola S. 2012, *Il Sistema Informativo Territoriale Archeologico di Roma SITAR*, «Archeologia e Calcolatori», 23, 31-50 (http://www.archcalc.cnr.it/indice/PDF23/02_Serlorenzi_et_al.pdf).

Serlorenzi M., Leoni G., Lamonaca F., Picciola S. 2021, *Il SITAR e le comunità degli utenti: un'infrastruttura culturale al servizio del patrimonio archeologico di Roma*, in F.R. Cerami, M.L. Scaduto, A. De Tommasi (eds.), *I bacini culturali e la progettazione sociale orientata all'heritage-making, tra politiche giovanili, innovazione sociale, diversità culturale, framework del Progetto ABACUS – Attivazione dei Bacini Culturali Siciliani, alla luce della Convenzione Quadro del Consiglio d'Europa sul valore del Patrimonio culturale per la società*, Firenze, All'Insegna del Giglio, 201-212 (https://www.insegnadelgiglio.it/prodotto/i-bacini-culturali/).

Tarantini M. 2014, *Firenze. Archivio storico della Soprintendenza Archeologia della Toscana: lavori di riordino e catalogazione*, «Notiziario della Soprintendenza per i Beni Archeologici della Toscana», 10, 218-219.

ABSTRACT

The MAGOH (Managing Archaeological data for a sustainable Governance of Heritage) project is a two-year project funded by Regione Toscana, co-funded by the Italian Ministry of Culture (MIC) and coordinated by MAPPA Lab of the University of Pisa. The project was designed to address the needs of the Superintendencies of Florence, Pistoia and Prato and of Pisa and Livorno to manage archaeological data. The project represents the development of the MAPPA project on a larger geographical area of 72,000 km², corresponding to almost all of Northern Tuscany. MAGOH system is composed of a web-based back-end which allows collecting textual and vector data and the archaeological documentation. It contains around 8000 archaeological interventions openly accessible through the web platform and reusable as open data following FAIR principles. Furthermore, through an appositively developed API, it is entirely interoperable with GNA, the National Geoportal for Archaeology, managed by the MIC.

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A STATUE OF ATHENA IN THE SANCTUARY OF APOLLO IN HIERAPOLIS (PHRYGIA): FROM THE FRAGMENTS TO THE 3D RECONSTRUCTION

1. Introduction

This article provides a preliminary presentation of a project centred on the sculptures from the main sacred area of Hierapolis in Phrygia, one of the larger settlements of Asia Minor. The excavations performed by the Italian Mission, which has been working at the site since 1957, brought to light hundreds of fragments, many of which were recovered from the levels corresponding to the abandonment and destruction of the site in the Byzantine era. These provide a database of great evidential value for the reconstruction of the statuary and the symbolic meanings that were expressed in it. For the management of this complex mass of information, a dedicated application was created, designed to support all the phases of the research. Of considerable importance is the use of three-dimensional reconstruction techniques, now applied in a growing number of fields including ancient sculpture. In the case in question, the adoption of these technologies proved to be particularly effective, since it has made it possible to compensate for the highly fragmentary nature of the materials, as illustrated in § 3-5.

G.S.

2. The sanctuary of Apollo and the context of discovery of the statue of Athena

The sanctuary dedicated to the main divinity of Hierapolis occupies a large space in the monumental heart of the city (Fig. 1). The research conducted in the last twenty years has made it possible to reconstruct its organisation and phases (summary in Semeraro 2014, 2016b), expanding and updating the limited evidence available before 2000, which resulted from the excavations conducted in the 1960s (Carettoni 1965; Ismaelli 2017 for the excavation data conserved in the Carettoni-Fabbrini private archive).

The area began to be used for cultic purposes as early as the Hellenistic period, coinciding with the foundation of the Greek colony of Hierapolis (towards the middle of the 3rd century BC; Ritti 2017, 274-277). However, it is clear that the monumentalisation took place in the Julio-Claudian period, to which Temple B, dedicated to the cult of Apollo, is also dated (Sacchi, Bonzano 2012).

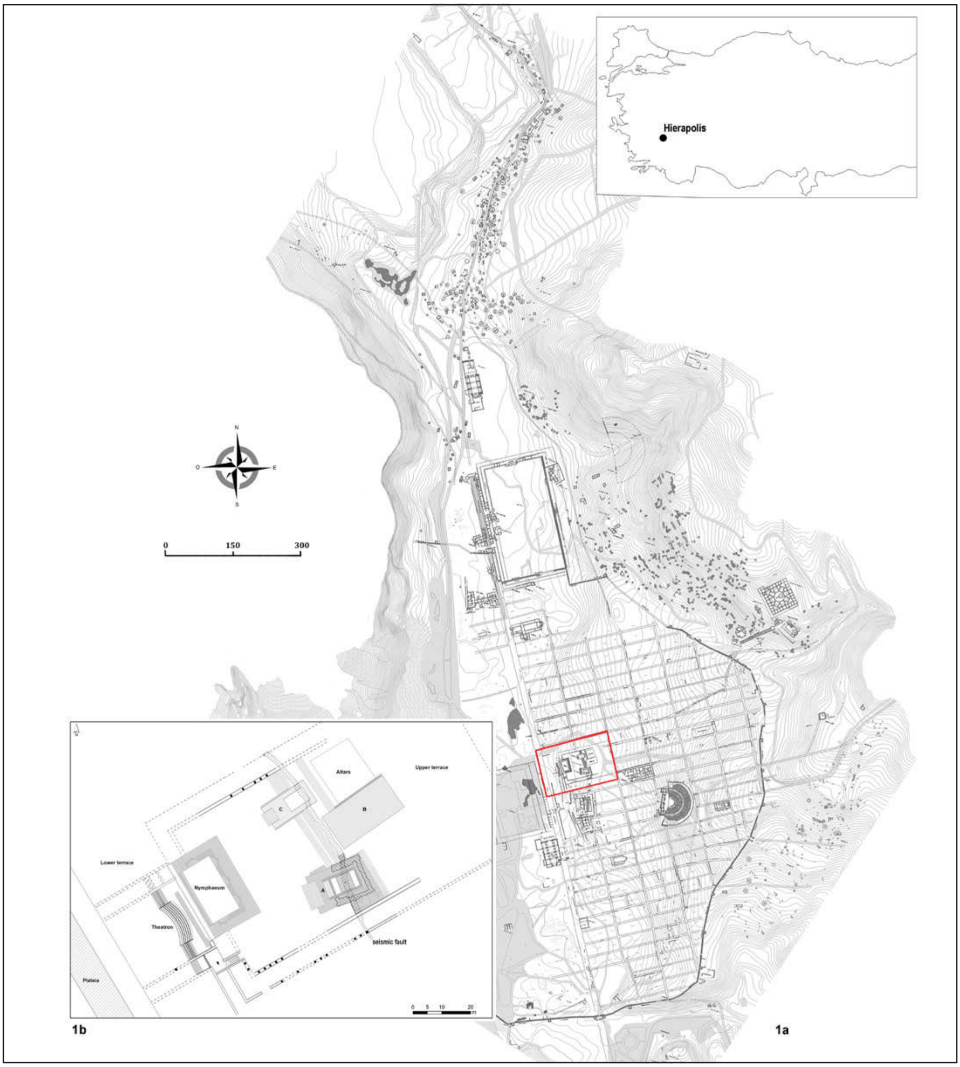

Fig. 1 – General plan of Hierapolis in Phrygia (a) showing the location and site plan (b) of the sanctuary of Apollo.

Most of the materials pertaining to the sculptural and architectural decoration of the Roman-era sanctuary are from the levels corresponding to the destruction and abandonment of the sacred area, a process that began in the 4th century AD, when the sanctuary was progressively dismantled and transformed into a dumping ground (Semeraro 2007).

The exploration of these levels made it possible to recover many elements useful for reconstructing the general layout of the sacred area in the various phases. The most extensively portion investigated to date corresponds to the median terrace, where three temple buildings stand (A, B and C) (Fig. 1b). The building most badly damaged by the removal of material in the Proto-Byzantine period is definitely Temple B, dedicated to the cult of the main divinity. The stratigraphic excavation made it possible to document a radical act of destruction that entailed the removal not only of the marble decoration, but also of a part of the travertine foundations. Indeed, part of the floor plan of the temple can be reconstructed only thanks to the ghost-walls (Semeraro 2007, 2016a). Some of the architectural elements that enable the reconstruction of the walls are conserved because they were reused in the hall of the Great Baths, built in the 4th century AD (Sacchi, Bonzano 2012), and some because they were placed in the deposits of marble blocks created behind buildings A and C in the Proto-Byzantine period with a view to using them as a source of building materials (Semeraro 2007).

Most of the statues recovered in the excavations of the 1960s came from the deposit behind building A (Bejor 1991). In contrast, the sculptural fragments identified by the excavations conducted from 2001 onwards come from the levels containing dumped materials (such as the head of an *euergetes* in Pellino 2012b) or had been reused to build structures in the Byzantine period (such as the fragments of a statue of Eros in Pellino 2012a and those of the statue in Semeraro 2021, 219, 223, fig. 16-10).

The context of discovery of the fragments of the statue of Athena discussed in this article is quite different. Indeed, they are from an extensive level dated to the Proto-Byzantine period, identified in front of Temple C and Temple B (Figs. 2-3), rich in marble fragments arising from the systematic destruction of architectural and sculptural elements, so small as to make identification of the objects to which they belonged extremely difficult. The layer covered the levels of the removal of the pavement in front of Temple C and the flight of steps in front of Temple B and was in turn covered by successive layers of dumped materials that accumulated in the course of the Proto- and Middle Byzantine periods. Given its composition, it can be ascribed to the destruction *in situ* of objects belonging to the sculptural decoration of the sanctuary. It can be concluded that the statue of Athena discussed in this note was probably originally positioned near the place where the fragments were discovered, perhaps in the space between the two Temples C and B.

As already noted (Semeraro 2007), these data point to systematic destruction, which it is difficult to explain without reference to ideological motives. The dismantling of the sanctuary, and the temple dedicated to Apollo in particular, is dated to the period that saw the rise of the new Christian

Fig. 2 – Hierapolis in Phrygia. View of the sanctuary of Apollo showing the location of the stratigraphic units in which the fragments of the statue of Athena were discovered.

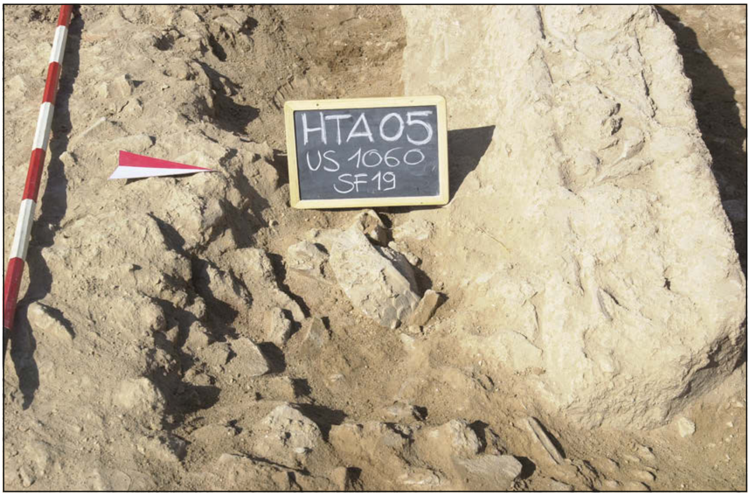

Fig. 3 – Hierapolis in Phrygia. Sanctuary of Apollo: fragment of the aegis of the statue of Athena at the moment of discovery in a layer of accumulated marble fragments and architectural elements.

religion, which in Hierapolis was centred on the cult of the apostle Philip, now documented in extraordinary fashion by the discovery of the saint's tomb (D'Andria 2017a, 2017b).

The fate of the temple of the main pagan divinity, along with the statues of the divinities with whom the *temenos* was shared, may thus be attributed to the spiritual climate that accompanied the birth of the new centre of Christianity. The statues are cited in the epigraphical attestations (collected in Ria 2022), while very little remains of the archaeological layers, as shown by the case of the fragments of the statue of Athena.

3. The sculptures of the sanctuary of Apollo: the research project

Launched in 2017, the project for a scientific edition of the sculptures of the sanctuary of Apollo is divided into a number of phases coordinated by the present author (Semeraro 2021, 223-224). The first phase of activity, undertaken in 2017-2019 with further work being conducted in 2021, took place in Pamukkale, at the headquarters of the MAIER, and entailed the systematic census and cataloguing of the sculptures discovered during the archaeological research of the 2000's. The next step of the project, dedicated to the study of the recorded evidence and a review of the already published materials (Bejor 1991, 49-61; Pellino 2012a, 2012b; Galli 2017), concluded with the creation of the *corpus* of the sanctuary's statues and reliefs. Today therefore, we have a complete catalogue of the sculptures of the sacred area. Integrated with the information provided by the inscribed bases from the monumental context (Nocita 2017; Ritti 2017, 355-409), it constitutes a body of data useful for reflecting on the function of statuary types and iconographic themes inside the sanctuary and for formulating hypotheses on the meaning of the figurative programme. Furthermore, an overview of the evidence highlights key elements for understanding both the role played by local *euergetai* and civic authorities in selecting the works of art that made up the sacred decoration, and the messages directed to the users of the sacred area, which served as imperial propaganda.

Lastly, considering the important results obtained by studies of the settlements of Asia Minor, where the study of the monumental complexes – especially the emblematic case of the Sebasteion of Aphrodisias (Smith 2013) – entails systematic comparison of sculptural and epigraphical data with those of the buildings, it seemed appropriate to adopt this type of approach in the case of Hierapolis as well. Indeed, the project's final and more ambitious objective is to produce hypotheses regarding the arrangement of the sculptural furnishings in the space that hosted the temples. This means reconstructing the image that the sanctuary of Apollo is believed to have presented to visitors in Imperial epoch, when the sacred place played a central role in the life of Hierapolis due as much to its key position in the urban layout as to the worship of the main polyadic divinity (D'Andria 2001, 2013; Semeraro 2008, 2016a).

As part of the project on the sanctuary of Apollo, the recorded sculptures were catalogued by means of a bibliographical review and research conducted both in the storage facilities of the MAIER and at the Archaeological Museum of Denizli-Hierapolis. This task was performed by Vincenzo Ria, who also set up a database of the DBMS type (Database Management System) using Microsoft Access. Compatible with the GIS platforms of the Italian Archaeological Mission, it holds data on statues, reliefs and inscribed and non-inscribed bases (Ria 2022). Today, the database holds records on 290 finds – 185 sculptures and 105 fragments of bases, 31 of which are inscribed, datable to the period from the late Republican age to the 3rd century AD – accompanied in many cases by the relevant virtual model (Ria 2022; *infra*, § 5). Three-dimensional models, specifically of the sculptures of the sanctuary of Apollo, constitute important work tools that facilitate the search for parallels, enabling the stylistic classification of pieces and the formulation of reconstructive hypotheses concerning statues and reliefs of which rarely more than a fragment is conserved.

The *corpus* of the sculptures from the sanctuary of Apollo is indeed mainly made up of portions of works of art, often of small dimensions, reduced to fragments in the Proto-Byzantine phase and discovered in secondary deposits in various points of the sacred area, either in dumps near the temples or reused in later constructions (Semeraro 2007; 2021, 223-224; *supra,* § 2). These works of art include reliefs with figures whose dimensions are nearly always smaller than life (male figures in heroic nudity and clothed females; erotes), as well as iconic and ideal statues that in some cases are larger than life (Ria 2022). Indeed, the sanctuary's iconic statuary, attested by the sculptural and epigraphical evidence, is highly complex.

The images of eminent local personages, *euergetai* (Pellino 2012b) and magistrates are accompanied by images of members of the imperial family, whose cult was probably practised in the sanctuary, as suggested by the inscription on the plinth of the female *capite velato* statue dedicated by the lady benefactor Apphias to the Dei Augusti and the *demos* (Bejor 1991, 54-55, no. 25; Galli 2017, 514-517). While sculptures of Trajan, Sabina, Julia Maesa and Julia Mamaea are attested by fragments of inscribed bases (Ria 2022), an exceptional piece of evidence is the colossal statue, only partly conserved, of Hadrian shown with the breastplate, next to a defeated barbarian, in a pose that clearly alludes to the theme of victory (Galli 2017, 517-522). Just as rich is the range of ideal statues, represented in works, some in small format, that in some cases reproduce famous masterpieces of the classical world, such as the Eros of Thespiae by Lysippos (Pellino

Fig. 4 – Hierapolis in Phrygia. Statue of Athena. Left shoulder covered by the aegis.

2012a). The images of divinities include the statue of Athena, discovered in a fragmentary state, the 3D reconstruction of which is presented for the first time in this paper.

4. The statue of Athena: description and analysis

Of the statue of Athena, made of crystal white marble, 65 fragments belonging to the helmet, hair, thorax and shoulders (covered by the aegis), both arms and the long garment are conserved (Figs. 4-6). The fragments vary greatly in terms of shape and size. The height ranges from 3 cm to 27.5 cm, with most of the finds between 7 and 20 cm. Just as varied is the state of conservation of the materials, whose surfaces are frequently affected by calcareous incrustations. The largest piece (27.5×21 cm) is composed of two joining fragments and corresponds to the left shoulder and the upper part of the goddess' humerus and back (Fig. 4). Her shoulder is covered by the aegis which hangs stiffly down the back. The arm, which is lowered and touches the side of the body, is covered by the light cloth of the chiton, which forms arched and parallel folds.

The surface of the aegis is covered by ovoid scales, each with a raised rib in the centre. The scales, in slight relief on the goddess' shoulder but flat on the back, are separate from each other and are arranged in an orderly pattern, with the point facing downwards, in staggered horizontal rows. This arrangement of the scales is seen on various fragments which have flat surfaces and thus belong to the rear part of the aegis (Fig. 5, below). In some cases, these fragments also conserve the lower edge of the aegis, underneath which the folds of the drapery can be distinguished. The fragments of the front of

Fig. 5 – Hierapolis in Phrygia. Statue of Athena. Fragments of helmet and hair (above); front of the aegis and raised right arm (centre); rear of the aegis (below).

Fig. 6 – Hierapolis in Phrygia. Statue of Athena. Fragments of peplos: upper part of the drapery (above); lower part of the drapery (below).

the aegis have different characteristics (Fig. 5, centre). Indeed, they have a curved surface, accentuated on the goddess' bust, with the scales rendered in a more plastic way, as well as varying in size and orientation, being arranged in irregular rows and overlapping in a disorderly way.

In contrast to the statue's lowered left arm, the right arm is raised to the level of the shoulder, as documented by a fragment showing the lateral part of the aegis and the humerus covered by the chiton (Fig. 5, centre). Numerous portions of the peplos worn over the chiton also remain. They conserve the drapery of the upper part, the folds of the *apoptygma* and the garment that covered the goddess' legs (Fig. 6). Lastly, recognisable in two fragments are Athena's helmet and hair (Fig. 5, above). Although we only have fragments of the Athena of Hierapolis, the surviving evidence enables us to establish the historic and artistic framework of the statue (on Athena and her images: Demargne 1984; Deacy, Villing 2001; Villing 2009).

The Athena of Hierapolis, of larger-than-life dimensions (a height of 2.10-2.20 m has been calculated, see *infra*, § 5), was carved so as to be viewed from all directions, as shown by the precision and detail of the individual fragments, including those belonging to the back of the statue. In order to reconstruct the volume, proportions and stance of the body, significant clues are provided by comparison with the colossal statue of Athena in Pentelic marble discovered in 1880 in the sanctuary of the goddess in Pergamon, which was subsequently taken to Berlin (AvP VII 24; Demargne 1984, 978, no. 230, 1041; Davison 2009, 187-189, no. 36; Niemeier 2016). A Hellenistic adaptation (*Umbildung*) of the chryselephantine Athena Parthenos created by Pheidias for the Acropolis of Athens, the Athena of Pergamon (3.10 m high without the base) is even more imposing than the Athena of Hierapolis.

However, while the two statues differ in terms of size, other elements point to a strong resemblance. These include the aegis, the invincible defence weapon that was one of the attributes of Athena, whose appearance in iconographic sources varies although it is always represented fringed with snakes and bearing the Gorgoneion (Vierck 1997; Robertson 2001).

Of the Gorgoneion and snakes that are believed to have featured on the aegis of the sculpture of Hierapolis no trace remains. They are seen on the aegis of Pergamon, which is legible despite gaps affecting the edges and the back, modelled and smooth.

The fragmentary state of the aegides of Hierapolis and Pergamon does not obscure their typological similarities. On both statues, the aegis is broad and is worn in such a way as to cover the shoulders and bust, following the curve of the breasts on the front and covering part of the back, where it takes the form of a rigid quadrangular cloak. This similarity between the two sculptures stands out even more now, thanks to the integrative restoration of the Berlin statue carried out in 2015 (Massmann, Will, Wegel 2018, 172-174).

The restoration reveals that in the Hierapolis and Pergamon statues, taking account of the different proportions, the breadth of the shoulders and the movement and edge of the aegis are the same.

This is important because it demonstrates that the goddess of Hierapolis wears the type of aegis attested in those adaptations, such as the Athena of Pergamon, which are believed to be very close to Pheidias' original Athena Parthenos (Demargne 1984, 977, nos. 220-221; Karanastassis 1987, 408-411, cat. BI 12-13; Vierck 1997, 511-512, type VIIa; Davison 2009, 170-172, 197-198, cat. 6.6, 6.7, 6.47, 6.48). The situation regarding the scales of the aegis is different however, since in terms of shape, size and the characteristics of the relief, the various reproductions of Pheidias' Parthenos differ from each other (Davison 2009, 81-83). The scales of the aegis of Hierapolis, viewed from the front, appear more plastic and are arranged more freely than those of the Pergamon Athena. The similarity of the Athena of Hierapolis to that of Pergamon is also seen in the rendering of the drapery. The two sculptures are both characterised by the long, straight vertical folds of the peplos. Separated by deep grooves, they run parallel to each other down the supporting right leg, creating light-and-dark effects (Fig. 6, below). The comparison can be extended to other parts of the garment.

Unlike the other statues inspired by Pheidias' Parthenos, which have bare arms and the upper arms lowered, in the Athena of Hierapolis the upper arms are covered by a chiton and the goddess is depicted with the left arm lowered and the right arm raised to the height of the shoulder. Thus, when conceiving the statue, the sculptor of the Athena of Hierapolis was inspired not only by Pheidias' Parthenos, but also by some other model. In terms of iconography, a statue of Athena discovered at Side (Asia Minor), sculpted at the beginning of the 3rd century AD, following a Hellenistic model, provides elements of comparison (İnan 1975, 142-145). The Athena of Side and that of Hierapolis share the position of the legs and the movement of the drapery, which is arranged in long folds on the supporting right leg. In addition, beneath the peplos, they both wear a sleeved chiton, visible in both cases on the lowered left arm. In the Side statue, as shown by a fragment of the hand, the left arm held a round shield; the right arm, which is not conserved, was raised and bent at the elbow in the act of holding the lance, traces of which remain on the base of the statue (Capaldi 2009, 33). It might thus be hypothesised that the Athena of Hierapolis held the shield in her lowered left arm and the lance in the raised right arm (the Athena of Pergamon but, as shown by the hole in the base of the statue, held the lance in her left arm: Niemeier 2016).

This combination of different models suggests that the Hierapolis statue was carved by a sculptor of the 'School of Aphrodisias', exponents of which were famous throughout the Roman world because they were able to reinterpret and fuse together different prototypes in the same work, producing works that were always original (Smith 2013; Van Voorhis 2018). The presence in Hierapolis of sculptures by artists from Aphrodisias is documented from the early Imperial epoch (Tomba Bella: Romeo, Panariti, Ungaro 2014) until the late-ancient period (*clipeus* with the portrait of Socrates: D'andria, Mannino 2007). For the statue of Athena in question, a dating to the Julio-Claudian period could be proposed. This is based on a comparison with certain reliefs among the rich series of sculptures that decorated the famous Sebasteion of Aphrodisias (Smith 2011, 2013). The sculptures of this prestigious architectural complex, dedicated to the cult of the *Theoi Sebastoi*, celebrated, by means of myth and allegory, the members of the imperial family, considered – in a perspective of the prosperity and eternity of the Roman empire – to be an integral part of the world of the heroes of Greece and the gods of Olympus. Among these sculptures there is a relief, badly damaged, that documents the presence in the Aphrodisias sculptors' repertoire of the standing Athena wearing a peplos, with the same arrangement of the legs as the statue of Hierapolis, holding the lance in her raised right hand and the circular shield in her lowered left hand (Smith 2011, cat. C13).

The meaning of the statue of Athena in the context of the sanctuary of Apollo in Hierapolis is not fully analysed here. It is important to stress that in the sanctuary of Apollo, the statue, positioned in the open air, plausibly between temples B and C (see *supra*, § 2), and displayed on a base that accentuated its size, making it visible from all angles, is believed to have played a similar role to the Athena of Pergamon. Displayed in the sanctuary of Athena, in the complex recognised as the Library founded by Eumenes II, the Athena of Pergamon had no shield, serpent or column with the Nike, as is clear from the base, which has only a hole for the lance: the statue thus lacked the distinctive attributes of the Parthenos created by Pheidias for Athens (Niemeier 2016, 132; Kästner 2018, 89; Niemeier 2018, 145). This consideration has prompted scholars to question whether the colossal image of Athena, positioned in the Library next to sculptures of illustrious intellectuals, was truly a cult statue: from this perspective, the presence of the goddess in that precise context could rather be explained as an emblem of wisdom and erudition as well as the patron of the arts (Karoglou 2016, 66; Niemeier 2016, 132).

The same function may be suggested for the Athena of Hierapolis in the sanctuary of Apollo, where it is also possible however that the goddess occupied a central position as the protector of the craftsmen who frequented the place of worship (their corporations are recorded in inscriptions discovered in the *hieron* and other contexts of the archaeological area: Ritti 2017, 148-156, 565-568).

K.M.

5. The statue of Athena: from the digital model of the fragments to the virtual reconstruction

The 3D model of the statue of Athena was created within the wider framework of the research into the sculptures of the sanctuary of Apollo in Hierapolis conducted by the present author as part of a thesis aimed at identifying elements useful for reconstructing the furnishings of the *hieron* (Ria 2022). In the systematic analysis of the sculptural finds of the sanctuary of Apollo, a considerable contribution was provided by digital technologies, which enabled the creation of virtual models of many of the fragments of statues and reliefs discovered in the *hieron*. Such models are useful for identifying parallels, but they will also ensure easy use of the finds kept in the MAIER's storage facilities in future. Indeed, one of the objectives of the thesis was to experiment with new forms of documentation and new ways of accessing the archaeological record that could be replicated in any context. This would help to resolve difficulties such as those that arose during the Covid-19 pandemic, when access to archaeological sites and materials being studied was severely limited.

In order to create the digital models of the fragments, the photogrammetric survey technique was applied (Fig. 7). This is a versatile tool used with increasing frequency because makes it possible to create virtual models of various classes of materials directly *in situ*. In the photogrammetric survey, the input used for the creation of the 3D models consisted of the images taken with a digital camera. In this case the restitution of the object is obtained via the projection in the three-dimensional space of points and lines generated by calculating the intersection of the optical lines derived from each photograph. The latter technique is used for the construction of geometric scale models complete with textures (Bianchini 2008).

The principle at the heart of this process is the same as that of stereoscopic photogrammetry, in which a pair of digital images of the same object, taken from two or more different viewing points, is used to create a three-dimensional representation of it (Panella, Gabrielli, Giorgi 2011, 247; Limoncelli 2012, 132). Photomodelling thus entails the acquisition of a series of photographic images with precise characteristics, including frames taken using a camera with a fixed focal length, and at least a 60% overlap between the various images. Fixed focal lenghts are more stable and less issues are caused with calibration. A zoom camera can be used though, especially with wide angle setting and stable zoom setting. In this case the user must be careful not to change the zoom during the photo shoot or the accuracy will be affected. The photographs thus acquired are then oriented by suitable software applications, including Metashape and Zephyr, within a system of spatial coordinates that makes use of control points shared across images.

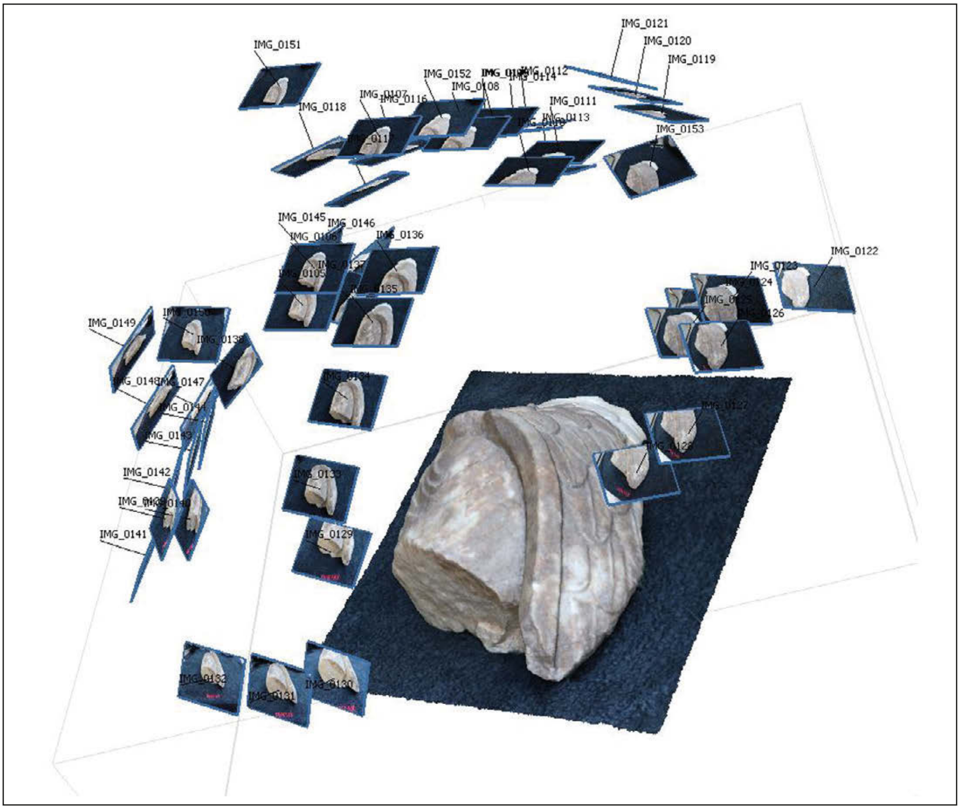

Fig. 7 – Statue of Athena from the sanctuary of Apollo (Hierapolis in Phrygia). Fragment of the shoulder with the aegis: digital model processed in Agisoft Metashape.

With the *in situ* surveying of archaeological buildings and stratigraphies, the acquired data can be extrapolated to a three-dimensional space with geographical coordinate by means of topographical survey tools such as total station or satellite-based radio navigation system like the GPS or the more accurated DGPS. In this case the result is a georeferenced metric virtual model on a scale of 1:1 (Bianchini 2008; Limoncelli 2012, 132). By means of photogrammetric survey it is possible to obtain two different types of output, configured as either a three-dimensional surface or a solid. The result in this case depends on the nature of the object and the way in which it was photographed. Specifically, while for reliefs, ceramic decoration and internal architectural features it is usually possible to achieve a three-dimensional representation of the surface, regarding all-round sculptures, external architectural features and mobile finds it is possible to perform a virtual survey of the entire solid

Fig. 8 – Statue of Athena from the sanctuary of Apollo (Hierapolis in Phrygia). Virtual positioning of the digitised fragments with reference to the 3D model of Athena Parthenos from Pergamon (https://www.myminifactory.com/object/3d-print-pergamon-athena-208722).

structure. The latter can be used to create physical reproductions of the object in question by means of 3D printing. Once the virtual model of the find or structure has been created, the use of suitable digital modelling software such as Blender and Cinema 4D makes it possible to act on various aspects of the 3D model, from the wireframe structure to the rendering of the textures. This in turn enables the generation of virtual reconstructive hypothesis, whose starting point is the digital model of the element in question.

In the specific case of the 160 selected sculptural fragments of the sanctuary of Apollo, this approach entailed taking a number of photographs *in situ* that were suited to the photogrammetric survey of each find and the subsequent conversion to a virtual model. The photographs were taken in the storage facilities of the MAIER and the Archaeological Museum of Denizli-Hierapolis using a Reflex Canon Eos 250D camera with an EF-S lens (18-55 mm). For each find for which a 3D model was required, 70-200 photographs were taken, depending on the size and complexity of the sculpture in question. The photographic sequences of each fragment, designed to cover the entire surface of the find, were then processed using Agisoft Metashape. For each sculptural find to be digitised, the photographs were aligned, the point cloud was generated and the polygonal meshes calculated.

Of the digitised finds, 65 – only 5 of which are contiguous – belong to the statue of Athena. In order to develop a hypothetical reconstruction of

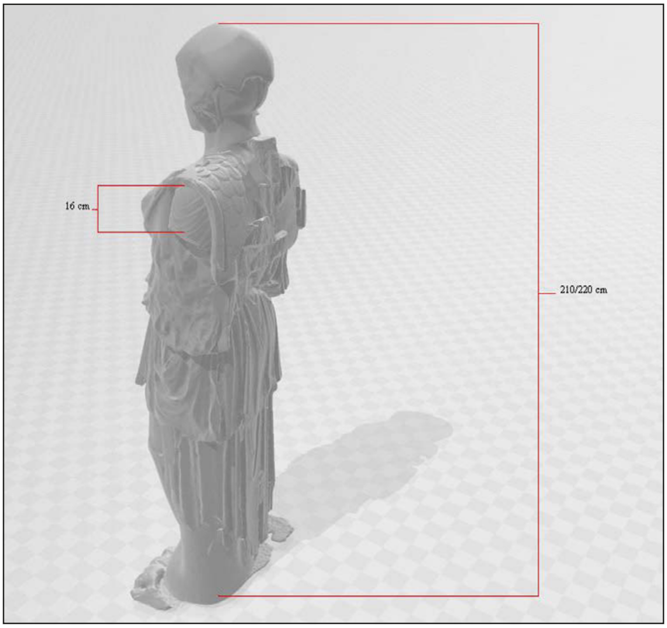

Fig. 9 – Statue of Athena from the sanctuary of Apollo (Hierapolis in Phrygia). Calculation of the statue's proportions on the basis of the digital positioning of the fragments.

the statue, the virtual models of the individual fragments were positioned with reference to the virtual model of Athena Parthenos from Pergamon (designed by J. Fisher and available on the digital model sharing platform https://www.myminifactory.com/), a sculpture identified as useful for reference and comparison on the basis of its stylistic features and the rendering of the aegis and the clothing. The positioning of the fragments, performed with the help of the open-source digital modelling application Blender, proved to be of fundamental importance. Indeed, the limited overall volume of the finds meant that by naked-eye observation alone they could only be generically attributed to the figure's aegis and clothing (four fragments belonged to the hair and the shoulders). In contrast, the use of digital technologies made it possible to precisely position 70% of the identified fragments (Fig. 8).

The work digitisation and virtual positioning of the fragments also made it possible to determine the sculpture's original height. Specifically, once the fragment of the left arm of the Athena from Hierapolis had been positioned with reference to the digital model of the statue from Pergamon, it was possible to compare the proportions of the surviving limb and the rest of the sculpture (Fig. 9).

It was thereby calculated that the statue of Athena from the sanctuary of Apollo was larger than life, with a total height of 2.10-2.20 m.

As well as the creation of virtual models of the fragments, the recourse to digital technologies as part of the research on the sculptures of the sanctuary of Apollo saw the start of experimentation with 3D printing as a means to physically reproduce the digitised finds. This entailed the use of both Fused Deposition Modelling (FDM), which has been deployed in museum contexts for some years now, and other innovative printing techniques including stereolithography. In both 3D printing systems, the various parts of the model are formed by means of the creation of a succession of layers, adhering one to the other, creating a solid stratification that constitutes the structure of the object. In more detail, FDM consists of depositing thermoplastic filaments, layer by layer, on the object as it is formed. Thermoplastic filaments such as PLA or ABS are extruded through a nozzle heated to between 220 and 250 °C and deposited in a semi-solid state on to the printing plane, where it tends to solidify in a few seconds (Kafle *et al.* 2021, 2-4).

In contrast, 3D printing by means of stereolithography (SLA) is based on photopolymerisation, a technique that uses bands of short-wave light (UV < 400 nm) to solidify the layers of resin inside a tank containing the liquid polymer (Melchels, Feijen, Grijpma 2010, 6121-6130; Kafle *et al.* 2021, 2-4).

The motif to be created is obtained using a laser beam controlled by the printer's firmware, which is projected on to the layer to be solidified, one after the other, thereby forming the three-dimensional model. In 3D printing of the SLA type, the thickness of the layer is determined by the quantity of energy emitted by the light source and the time of exposure of the resin to the ultraviolet source.

Despite the greater complexity of the printing and post-production phases, this 'additive manufacturing' technology has numerous advantages over FDM 3D printing techniques. For example, using SLA 3D printing, it is possible to obtain models with ten times the level of detail with respect to FDM, a difference that translates into a rendering of the surfaces that perfectly reflects the original model. In this case, the 3D printing of both the individual fragments and the proposed reconstruction of the sculptures such as the statue of Athena sought to evaluate new ways to support future heritage projects. These range from the non-invasive restoration of finds (by 3D printing the missing parts) to the creation *ex novo* of reconstructive hypotheses (by 3D printing the entire model), to be positioned *in situ*. The latter approach has already been successfully followed in the context of Hierapolis, as part of the restoration of the adjacent cultic complex of the Ploutonion. In this case, a hypothetical reconstruction of the colossal statue of Hades with Cerberus, discovered in the course of the excavations conducted in the area, was created by carving marble blocks in the shape of the three-dimensional model generated from the laser scanning surveys of the discovered fragments (D'Andria 2019).

A further innovative potential use involves the insertion of reproductions in 'phygital' displays in which the archaeological context or museum space is completed by digital media and interactive tactile installations.

V.R.

6. Conclusions

The case study discussed in the preceding paragraphs makes it possible to highlight the significant contribution of digital applications to the study project centred on the sculptures of the sanctuary of Apollo in Hierapolis. Indeed, digital technologies have played a fundamental role in the research since the start, facilitating the registration and management of the acquired data, with the aim of reconstructing the arrangement of the sculptural furnishings in the area of the temples. Of particular interest is the use of 3D modelling techniques to reconstruct the sculptures' original appearance despite their extremely fragmentary condition. The method applied, discussed in this paper with reference to the marble statue of Athena, discovered in a highly fragmentary state in the 2005 and 2006 excavation campaigns, complements the detailed historical, artistic and iconographic analysis, using digital reconstruction and restoration technologies to produce working hypotheses that get as close as possible to reality. It was thus possible to reconstruct an image of the goddess by means of comparison with the famous statue of Athena in the Library of Pergamon, making a considerable contribution to the reconstruction of the cultic landscape of the sanctuary of Apollo in Hierapolis. Indeed, by virtually placing the tiny fragments of marble in their exact position, it was possible to digitally reconstruct an image in the round of the statue, which is believed to have stood in the open-air outside the cult buildings. Starting from these observations, it will be possible to formulate more precise reflections on both the role of the statue of Athena inside the *temenos* and the symbolic relationships between the important cities of Hierapolis and Pergamon in Asia Minor.

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REFERENCES

Bejor G. 1991, *Le Statue*, *Hierapolis. Scavi e Ricerche*, III, Roma, Giorgio Bretschneider Editore.

Bianchini M. 2008, *Manuale di rilievo e di documentazione digitale in archeologia*, Roma, Aracne.

Capaldi C. 2009, *Statua di Atena*, in C. Gasparri, C. Capaldi, S. Pafumi (eds.), *Le sculture Farnese*, 1, *Le sculture ideali*, Napoli, Electa, 33-34.

Carettoni G. 1965, *Scavo del tempio di Apollo a Hierapolis (rapporto preliminare)*, «Annuario della Scuola Archeologica di Atene e delle Missioni Italiane in Oriente», 41-42, n.s. XXV-XXVI, 411-433.

D'Andria F. 2001, *Hierapolis of Phrygia: Its evolution in Hellenistic and Roman times*, in D. Parrish (ed.), *Urbanism in Western Asia Minor: New Studies on Aphrodisias, Ephesos, Hierapolis, Pergamon, Perge and Xanthos*, «Journal of Roman Archaeology», Supplementary Series, 45, 96-115.

D'Andria F. 2013, *Il Ploutonion a Hierapolis di Frigia*, «Istanbuler Mitteilungen», 63, 157-217.

D'Andria F. 2017a, "*Hierapolis alma Philippum*". *Nuovi scavi, ricerche e restauri nel Santuario dell'Apostolo*, «Atti della Pontificia Accademia di Archeologia. Rendiconti», 89, 129-177.

D'Andria F. 2017b, *The Sanctuary of St Philip in Hierapolis and the tombs of saints in Anatolian cities*, in J.R. Brandt, E. Hagelberg, G. Biørnstad, S. Ahrens (eds.), *Life and Death in Asia Minor in Hellenistic, Roman and Byzantine Times. Studies in Archaeology and Bioarchaeology*, Oxford-Philadelphia, Oxbow Books, 3-18.

D'Andria F. 2019, *Il racconto di Hierapolis: tra innovazione e tecnologie digitali*, in A. Polosa, H.H.A. Kızılarslanoğlu, M. Oral (eds.), *SEBASTE. Studies in honour of Eugenia Equini Schneider*, Istanbul, Ege Yayınları, 193-203.

D'Andria F., Caggia M.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., Mannino K. 2007, *Socrate a Hierapolis di Frigia*, in E. Öztepe, M. Kadıoğlu (eds.), *PATRONUS. Festschrift für C. Özgünel zum 65. Geburtstag*, Istanbul, Betül Avunç, Homer Kitabevi, 133-140.

Davison C.C. 2009, *Pheidias*: *The sculptures and ancient sources*, 1-3, «Bulletin of the Institute of Classical Studies», Suppl. 105.

Deacy S., Villing A. (eds.) 2001, *Athena in the Classical World*, Leiden-Boston, Brill.

Demargne P. 1984, s.v. *Athena*, in *Lexicon Iconographicum Mythologiae Classicae*, II, 1, 955-1044.

Galli M. 2017, *I ritrovamenti scultorei dagli scavi Carettoni-Fabbrini nel Santuario di Apollo*, in Ismaelli 2017, 510-524.

İnan J. 1975, *Roman Sculpture in Side,* Ankara, Türk Tarih Kurumu Basımevi.

Ismaelli T. 2017, *Hierapolis di Frigia X. Il Tempio A nel Santuario di Apollo. Architettura, decorazione e contesto*, Istanbul, Ege Yayınları.

Kafle A., Luis E., Silwal R., Pan H.M., Shrestha P.L., Bastola A.K. 2021, *3D/4D printing of polymers: Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA)*, «Polymers», 13, 3101 (https://doi.org/10.3390/polym13183101).

Karanastassis P. 1987, *Untersuchungen zur kaiserzeitlichen Plastik in Griechenland. II: Kopien, Varianten und Umbildungen nach Athena-Typen des 5. Jhs. v.Chr.*, «Mitteilungen des Deutschen Archäologischen Instituts, Athenische Abteilung», 102, 323-428.

Karoglou K. 2016, *Trends in Hellenistic sculpture*, in Picón, Hemingway 2016, 62-69.

Kästner V. 2018, *Das Heiligtum der Athena*, in Scholl, Schwarzmaier 2018, 82-91.

Limoncelli M. 2012, *Il restauro virtuale in archeologia*, Roma, Carocci.

Massmann W., Will A., Wegel N. 2018, *Restaurierungsmassnahmen an pergamenischen Marmorstatuen: Drei Fallbeispiele für Ergänzungen und Rekonstruktionen*, in Scholl, Schwarzmaier 2018, 172-179.

Melchels F.P.W., Feijen J., Grijpma D.W. 2010, *A review on stereolithography and its applications in biomedical engineering*, «Biomaterials», 31, 6121-6130 (https://doi.org/10.1016/j.biomaterials.2010.04.050).

Niemeier J.-P. 2016, *Statue of Athena Parthenos*, in Picón, Hemingway 2016, 132-133.

Niemeier J.-P. 2018, *Pergamon und der hellenistische Klassizismus*, in Scholl, Schwarzmaier 2018, 143-149.

Nocita M. 2017, *Le iscrizioni dagli scavi Carettoni-Fabbrini nel Santuario di Apollo*, in Ismaelli 2017, 457-484, 485-508.

Panella C., Gabrielli R., Giorgi C. 2011, *Le "Terme di Elagabalo" sul Palatino: sperimentazione di un metodo fotogrammetrico 3D applicato allo scavo archeologico*, «Archeologia e Calcolatori», 22, 243-260 (http://www.archcalc.cnr.it/indice/PDF22/AC_22_Panella_et_al.pdf).

Pellino G. 2012a, *Eros in area Apollinis. Una copia dell'Eros tipo Tespie e l'arredo scultoreo del Santuario di Apollo*, in D'Andria, Caggia, Ismaelli 2012, 359-372.

Pellino G. 2012b, *Un ritratto virile d'età augustea dal Santuario di Apollo: l'immagine di un evergete ierapolitano di I sec. a.C.?*, in D'Andria, Caggia, Ismaelli 2012, 373-385.

Picón C.A., Hemingway S. (eds.) 2016, *Pergamon and the Hellenistic Kingdoms of the Ancient World*, Catalogo della mostra, New York, Metropolitan Museum of Art.

Ria V. 2022, *Il Santuario di Apollo a Hierapolis di Frigia: analisi delle sculture e ricostruzione del programma figurativo dell'area sacra*, Tesi di Dottorato di Ricerca in Scienze del Patrimonio Culturale, XXXIV Ciclo, Università del Salento.

Ritti T. 2017, *Hierapolis di Frigia IX. Storia e istituzioni di Hierapolis*, Istanbul, Ege Yayınları.

Robertson N. 2001, *Athena as weather goddess: The aigis in myth and ritual*, in Deacy, Villing 2001, 29-55.

Romeo I., Panariti D., Ungaro R. 2014, *La Tomba Bella: un heroon giulio-claudio e il suo sarcofago*, Istanbul, Ege Yayınları.

Sacchi F., Bonzano F. 2012, *L'ordine del Tempio di Apollo a Hierapolis: prime acquisizioni*, in D'Andria, Caggia, Ismaelli 2012, 325-357.

Scholl A., Schwarzmaier A. (eds.) 2018, *Pergamon: Meisterwerke der antiken Metropole und 360° Panorama von Yadegar Asisi*, Begleitbuch zur Ausstellung, Berlin, Michael Imhof Verlag, Antikensammlung der Staatlichen Museen zu Berlin.

Semeraro G. 2007, *Ricerche archeologiche nel Santuario di Apollo (Regio VII), 2001-2003*, in F. D'Andria, M.P. Caggia (eds.), *Hierapolis di Frigia, I. Le attività delle campagne di scavo e restauro 2000-2003*, Istanbul, Ege Yayınları, 169-209.

Semeraro G. 2008, *The Sanctuary of Apollo in Hierapolis. A stratigraphical approach to a cult context,* in *Uluslararası Antik Dönemde Kehanet ve Apollon'un Anadolu Kültleri Sempozyum Bildirileri (İzmir 2005)*, Arkeoloji dergisi, 2, İzmir, Ege Universitesi, 179-190.

Semeraro G. 2014, *Archaeology of the cult in the Sanctuary of Apollo in Hierapolis*, «Scienze dell'Antichità», 20, 2, 11-29.

Semeraro G. 2016a, *Ricerche nel Santuario di Apollo (2007-2011)*, in F. D'Andria, M.P. Caggia, T. Ismaelli (eds.), *Hierapolis di Frigia VIII,1. Le attività delle campagne di scavo e restauro 2007-2011*, Istanbul, Ege Yayınları, 191-222.

Semeraro G. 2016b, *The Sanctuary of Apollo in Hierapolis: Building activities and ritual paths*, in T. Ismaelli, G. Scardozzi (eds.), *Ancient Quarries and Building Sites in Asia Minor. Research on Hierapolis in Phrygia and Other Cities in South-Western Anatolia: Archaeology, Archaeometry, Conservation*, Bari, Edipuglia, 777-785.

Semeraro G. 2021, *Hierapolis of Phrygia 2018-2020: Recent work and new perspectives*, in S.R. Steadman, G. McMahon (eds.), *The Archaeology of Anatolia, Volume IV: Recent Discoveries (2018-2020)*, Newcastle upon Tyne, Cambridge Scholars Publishing, 210-228.

Smith R.R.R. 2011, *Marble workshops at Aphrodisias*, in F. D'Andria, I. Romeo (eds.), *Roman Sculpture in Asia Minor, Proceedings of the International Conference to Celebrate the 50th Anniversary of the Italian Excavations at Hierapolis in Phrygia (Cavallino-LE 2007)*, «Journal of Roman Archaeology», Supplementary Series, 80, 62-76.

Smith R.R.R. 2013, *The Marble Reliefs from the Julio-Claudian Sebasteion, Aphrodisias VI: Results of the Excavations at Aphrodisias in Caria Conducted by New York University*, Darmstadt, Verlag Philipp von Zabern.

Van Voorhis J. 2018, *The Sculptor's Workshop*, *Aphrodisias X*, Wiesbaden, Reichert Verlag.

Vierck S. 1997, s.v. *Aigis*, in *Lexicon Iconographicum Mythologiae Classicae*, VIII, 1, 510-515.

Villing A. 2009, s.v. *Athena*, in *Lexicon Iconographicum Mythologiae Classicae*, Suppl., 107-123.

ABSTRACT

In 2005-2006 the excavations in the Sanctuary of Apollo conducted by the Italian Archaeological Mission in Hierapolis in Phrygia (MAIER) brought to light about sixty fragments of a larger-than-life marble statue of Athena. This paper presents the discovery, highlighting the role played in the research by digital technologies, especially 3D modelling and reconstruction techniques, the application of which mitigated the highly fragmentary nature of the evidence. The first section of the paper highlights the importance of the context of discovery of the fragments, which were found, together with other sculptural and architectural elements, in front of Temple B, in a deposit of discarded material related to the destruction *in situ* of part of the sanctuary's decorations in the Byzantine period. The second section describes the plan drawn up by the MAIER to publish a comprehensive scientific description of the sculptures of the Sanctuary of Apollo. The project aims to reconstruct the sculptural decoration of the sacred area in the Imperial period, combining information on the types of statuary and the iconographic subjects and themes with excavation data and the epigraphical documentation from the sacred area. The project includes the study of the statue of Athena, for which this paper provides the description and the results of the historic and artistic analyses. The final section is centered on the process that led from the creation of the digital model to the virtual reconstruction of the statue of Athena and, lastly, to the 3D printing of the reconstructive hypothesis. Digital models were created for many of the sculpture fragments of the Sanctuary of Apollo. Saved in a database designed to store data on the sculptures, these models facilitate the study of the documentation and have proved to be extremely useful for the dissemination of the finds to the public, especially in problematic situations that limit or impede access to the evidence, as was the case during the Covid-19 pandemic.

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METODOLOGIE INTEGRATE PER LO STUDIO E LA RICOSTRUZIONE DELLA QUADRIGA BRONZEA DI ERCOLANO NEL MUSEO ARCHEOLOGICO NAZIONALE DI NAPOLI

1. Introduzione

La quadriga bronzea di Ercolano, conservata nel Museo Archeologico Nazionale di Napoli, rappresenta una delle opere più enigmatiche che ci siano giunte dell'arte romana, per le incertezze che da sempre gravano sulla sua conoscenza, interpretazione e datazione. Recuperata in centinaia di frammenti in momenti diversi della storia degli scavi ercolanesi a partire dal 1739, essa è stata poco indagata ed è rimasta prevalentemente relegata nei depositi del museo, senza che sia stato mai possibile giungere ad una sua soddisfacente ricostruzione archeologica né, tanto meno, ad una sua reale ricomposizione. L'unico studio che le sia stato dedicato è quello di Ettore Gabrici (1907), cui si deve il merito di aver eseguito per la prima volta un'importante scrematura tra le centinaia di frammenti statuari bronzei esistenti nei depositi del museo e di averne promosso una campagna fotografica. Da allora nessuno ha più intrapreso in maniera sistematica lo studio del monumento, sebbene esso venga sempre evocato in riferimento ai contesti monumentali di Ercolano (teatro, foro, Basilica Noniana) ai quali in passato si è ritenuto di poterla assegnare. Studi successivi hanno preso in esame singole tipologie di elementi figurativi riconducibili alla decorazione del carro o dei baltei dei cavalli (Cerulli Irelli 1972; Kreilinger 1996).

In verità, la ricostruzione archeologica della quadriga è stata sempre ostacolata da fattori che hanno reso difficile il riconoscimento dei frammenti di sicura pertinenza tra quelli esistenti nei depositi e questo ha forse favorito il proliferare di versioni contrastanti e fantasiose anche sul suo aspetto (quadriga o biga?). Non aiuta, infatti, la confusione generatasi nei rapporti di scavo settecenteschi per la contemporanea presenza degli scavatori borbonici in diversi punti della città e, d'altra parte, anche le movimentazioni all'interno dei depositi hanno fatto sì che quanto si è conservato del monumento, sopravvivendo alla distruzione del vulcano e sfuggendo al destino della rifusione, si mescolasse a frammenti statuari di tipologia equestre provenienti da altri contesti monumentali ercolanesi (Pafumi 2019; 2020, 94-100).

Oltre a ciò, si deve riconoscere che i problemi interpretativi che ruotano intorno al monumento in esame sono tanti e di tale complessità da avere probabilmente scoraggiato a lungo gli specialisti. Essi vanno: 1) dalla ricomposizione iconografica e strutturale dei manufatti che componevano la quadriga, alla loro corretta valutazione tecnica, artistica e stilistica nel panorama della statuaria bronzea di età romana; 2) dall'analisi del contesto monumentale per il quale essa fu commissionata e realizzata, all'interpretazione della sua funzione semantica e celebrativa; 3) dalla sua corretta collocazione cronologica, alla possibilità di riconoscere un'officina o una probabile area di produzione; 4) dall'individuazione delle operazioni necessarie per la conservazione e il restauro, allo studio delle strategie per un corretto ed efficace progetto espositivo.

La ripresa delle indagini si deve ad un accordo siglato sul finire del 2020 tra il Museo Archeologico Nazionale di Napoli e l'Istituto di Studi sul Mediterraneo del CNR, dal quale è scaturito un nuovo progetto scientifico, a guida di chi scrive, con l'obiettivo di giungere finalmente ad una più attendibile e controllata ipotesi ricostruttiva del monumento rispetto al passato[1]. Il progetto nasceva, inoltre, con il compito di facilitare il programma di restauro dei frammenti più significativi ai fini della ricomposizione del monumento, in vista del programmato nuovo allestimento espositivo delle sale dedicate alla statuaria proveniente dai contesti pubblici delle città campane, nell'ala SO del Museo Archeologico Nazionale di Napoli (sezione Campania romana).

Tenendo conto delle necessità finali di progetto e della tempistica imposta, una riflessione sul metodo e la progettazione dettagliata delle attività sono state fondamentali (Fig. 1). L'approccio metodologico prescelto è stato da subito rivolto non solo allo studio storico-archeologico del monumento e delle sue parti, ma anche alla verifica metrica, stilistica e morfologica dei singoli frammenti recuperati, in modo da poter giungere più velocemente all'elaborazione di un prodotto finale, inteso come modello di base per la conoscenza del manufatto, che non solo fosse utile agli specialisti archeologi per le finalità di studio, ma che potesse anche indirizzare il programma di restauro e di conservazione del museo e, quindi, la fruizione da parte del pubblico dei risultati della ricerca.

Questo contributo intende presentare, in particolare, le scelte metodologiche e le attività messe in campo per giungere alla proposta di ricomposizione della quadriga costruita mediante l'ausilio delle più recenti strategie e

[1] L'accordo operativo di collaborazione tra il Museo Archeologico Nazionale di Napoli e l'Istituto di Studi sul Mediterraneo del CNR per lo "Studio, ricostruzione e valorizzazione della quadriga bronzea di Ercolano" rientra nello sviluppo del progetto espositivo previsto al punto A.1.1 "Progettazione allestimenti digitali e multimediali, produzione contenuti digitali e ricostruzioni digitali in 3D" sulla voce A.1 "Allestimento tecnologico delle sezioni Museali" del QE del Progetto "Applicazione di modalità e strumenti innovativi in relazione al sistema dei servizi di accoglienza e di supporto alla fruizione degli attrattori e creazione di strumenti per gestire e promuovere i sistemi delle conoscenze degli attrattori", finanziato dal PON CULTURA E SVILUPPO FESR 2014/20 al MANN. Le attività di ricerca ricadono all'interno del progetto scientifico "La quadriga bronzea di Ercolano: studio, ricostruzione e valorizzazione" attivo presso l'ISMED-CNR (DUS.AD017.141), a responsabilità di chi scrive.

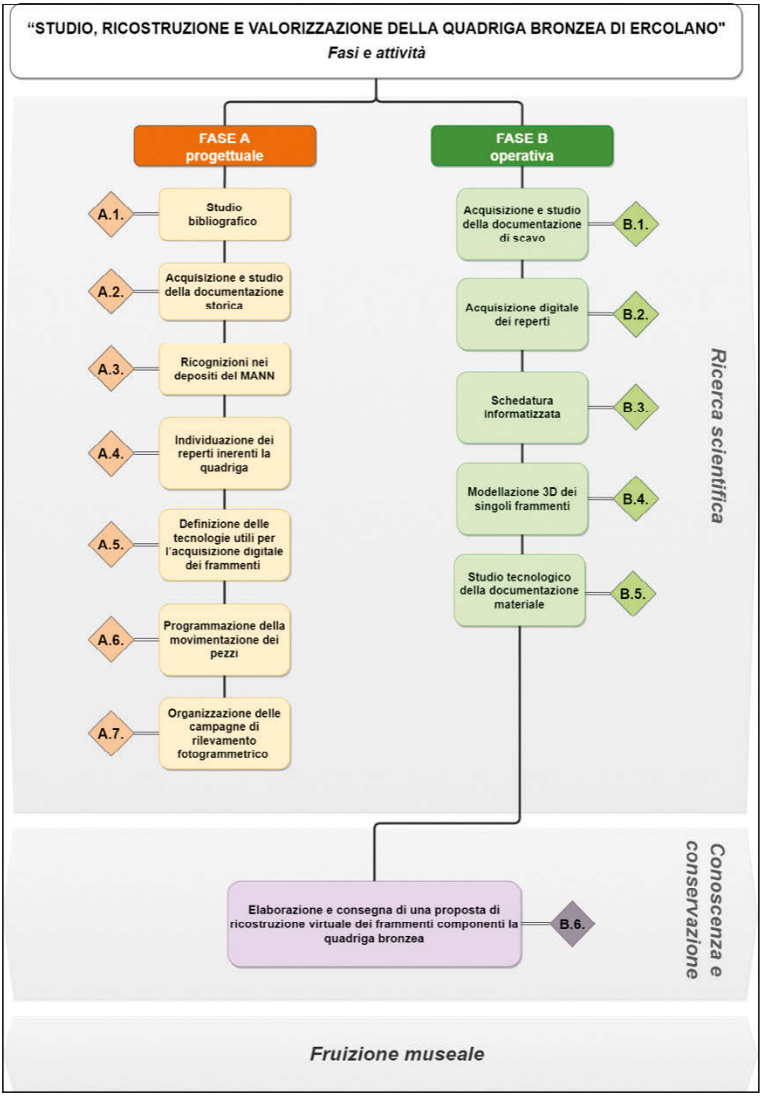

Fig. 1 – Diagramma delle fasi progettuali con le relative attività nel contesto degli obiettivi della ricerca.

tecnologie di acquisizione digitale su base 3D, mentre rimanda ad altra sede la discussione più ampia e dettagliata di tutti i risultati della rilettura critica, sia di carattere storico-archeologico che tecnico, cui si è pervenuti e ai quali in questa sede, per brevità, verrà fatto solo un rapido cenno.

2. Un approccio interdisciplinare alla ricostruzione

Il progetto di studio e ricostruzione della quadriga di Ercolano nel Museo Archeologico Nazionale di Napoli è stato fondato su percorsi di ricerca scientifica complementari che hanno proceduto di pari passo con la creazione dei contenuti digitali: da un lato, quelli propri della ricerca storico-archeologica, volti all'analisi filologica dei dati desumibili dalle fonti storiche e allo studio analogico, tipologico-funzionale e iconografico-stilistico della documentazione materiale sopravvissuta; dall'altro, quelli di carattere interdisciplinare, costruiti attraverso l'interazione fra i ricercatori, volti alla verifica delle ipotesi di ricostruzione del monumento attraverso l'ausilio della simulazione virtuale. Dall'integrazione di questi diversi percorsi della ricerca è scaturito l'approccio metodologico su cui si fonda, in questo studio, il processo conoscitivo della quadriga attraverso lo studio tridimensionale delle sue parti strutturali e decorative e la loro ricomposizione digitale. L'applicabilità di tale approccio alla grande statuaria bronzea, quando pervenutaci come nel nostro caso attraverso sufficiente documentazione, seppure molto frammentaria e lacunosa, rappresenta una risorsa di metodo di grande impatto, perché capace di produrre risultati non raggiungibili con l'impiego dei soli mezzi offerti dalle indagini di tipo tradizionale.

Nel nostro caso, la riflessione sul metodo si è resa ancora più necessaria perché, come si è già detto, sulla quadriga di Ercolano non esisteva una tradizione di studi e il dibattito non si è mai sviluppato su basi scientifiche veramente solide e ampie. L'unica ipotesi ricostruttiva esistente – quella avanzata nello studio monografico di E. Gabrici nel 1907 – si limitava a fornire un elenco di frammenti e a suggerire un'interpretazione che, seppur basata su un rigore scientifico soddisfacente per l'epoca in cui è stata prodotta, non è sembrata del tutto convincente. A ben guardare, infatti, essa presentava criticità sia sul piano dell'interpretazione dei dati storici, sia sul piano dell'interpretazione della documentazione materiale sopravvissuta. Basti citare, tra gli elementi più controversi e suscettibili di revisione, l'interpretazione come Apollo di una delle figure decorative del carro – quella in *Hüftmantel* (inv. n. 5016) – non più accettata nella letteratura successiva, e la ricostruzione della statua posta sul carro, identificata con Augusto/Sol (Gabrici 1907). Quest'ultima, sebbene plausibile, è apparsa quanto meno problematica, non tanto per le dimensioni maggiori del vero, che pure troverebbero spiegazione nella visione dal basso del monumento, quanto per il tipo statuario in nudità eroica, il cui utilizzo, insolito per la tipologia canonica del monumento trionfale, richiedeva di certo un approfondimento.

Non occorre, poi, ricordare che il prosieguo delle ricerche ad Ercolano, dopo il 1907, ha aggiunto numerosi elementi alla discussione, sia per l'accrescimento della documentazione materiale (specialmente a seguito degli scavi degli anni '60), sia per una più completa lettura e interpretazione critica dei contesti architettonici e monumentali che insistono nell'area in cui è stata rinvenuta la maggior parte dei pezzi della quadriga (in generale Wallace-Hadrill 2011, con ampia bibl. precedente). È apparso, dunque, evidente che nel nostro progetto di ricostruzione non sarebbe stato possibile seguire *in toto* la proposta avanzata dal Gabrici, né rigettarne qualche parte, senza aver prima effettuato una valutazione sistematica dell'intera documentazione superstite e senza aver prima sgombrato il campo da considerazioni di carattere pregiudiziale stratificatesi nel tempo.

Si è deciso, pertanto, di ripartire dal vaglio attento e sistematico di tutte le fonti disponibili e di tutte le ipotesi formulabili e verificabili attraverso la simulazione virtuale e il restauro digitale. In considerazione di ciò è sembrato opportuno elaborare una strategia di lavoro che permettesse di gestire man mano i dati scaturiti dalle indagini, mediante l'utilizzo di supporti informatizzati creati *ad hoc*, in modo da rendere più semplice la messa a sistema delle informazioni, la loro verifica incrociata e la loro disponibilità per studi ulteriori.

3. Percorsi della ricerca storico-archeologica

3.1 *Il regesto delle fonti*

Innanzitutto, si è proceduto ad una completa rilettura dei dati storico-archeologici ricavabili dai resoconti e diari di scavo e da altre fonti documentali, sia edite che inedite, al fine di predisporre una nuova, esauriente e riutilizzabile base documentaria sulla quadriga bronzea di Ercolano e sulla sua storia antica e post-antica.

Sono stati sottoposti al vaglio i documenti d'archivio disponibili sugli scavi borbonici, dalle relazioni dei protagonisti alle testimonianze coeve di varia natura; si è proceduto poi alla verifica delle informazioni relative agli scavi post-unitari e novecenteschi, fino ad arrivare agli interventi più recenti che hanno interessato anche negli ultimi decenni l'area dei ritrovamenti riferibili alla quadriga.

Il processo di revisione incrociata si è rivelato in generale assai complicato e laborioso per la peculiarità degli scavi ercolanesi che, soprattutto nel XVIII secolo, furono condotti contemporaneamente in luoghi diversi della città e a più riprese negli stessi luoghi, con il risultato di una inevitabile confusione nella registrazione dei rinvenimenti e di oscillazione nella loro successiva assegnazione ai diversi contesti della città da parte degli archeologi.

La ricerca condotta in questa direzione ha prodotto buoni risultati. Da un lato, una migliore e più completa lettura dell'aspetto complessivo della quadriga e dei suoi caratteri tipologici, grazie alla possibilità di arricchire l'elenco dei frammenti ad essa riconducibili una volta riconosciuta, per la presenza di elementi complementari, la pertinenza di nuclei di reperti rinvenuti anche a notevole distanza di tempo e spazio. Dall'altro lato, una maggiore chiarezza sul luogo di provenienza e di utilizzo della quadriga nel contesto monumentale della città.

La localizzazione del gruppo più cospicuo e compatto di frammenti – quelli recuperati nel 1739 – può essere, infatti, definitivamente fissata nella zona più prossima all'incrocio tra il *decumanus maximus* e il III *cardo* superiore, nella quale insistono alcuni degli edifici pubblici più importanti della città antica (*Augusteum*, Basilica Noniana, Sacello degli Augustali), in gran parte indagati solo attraverso i cunicoli degli scavi borbonici (Allroggen-Bedel 1974, 2008; Esposito, Camardo 2013). In questa zona corrispondente all'angolo NE dell'insula VII si è scavato, a partire da un pozzo di discesa, nel 1739 (ma non si possono escludere sporadici interventi precedenti) e, a più riprese, anche nel decennio 1740-1750 e in un'area prossimale anche nel 1762-1763, sotto la direzione di Rocque Joaquim de Alcubierre, Pierre Bardet, Karl Weber e Francesco La Vega (Ruggiero 1885; Pannuti 1983; Parslow 1995; Pagano 2005). L'area è stata poi lambita dagli scavi del 1960-1961 condotti alla sommità e lungo il III *cardo* superiore (*Giornali degli scavi*, conservati presso l'Ufficio Scavi di Ercolano e Archivio Storico della Soprintendenza Archeologica di Napoli), per arrivare, infine, alle indagini recenti promosse soprattutto nel 2009 dall'*Herculaneum Conservation Project* (Wallace-Hadrill 2011; Esposito, Camardo 2013).

L'altro grosso nucleo di frammenti riconducibili alla quadriga proviene dagli scavi a cielo aperto del 1871-1872 diretti da Giuseppe Fiorelli nei terreni dell'insula VII posti più a valle, tra il Vico di Mare e il *decumanus* inferiore e presso il quadrivio formato dal *decumanus* inferiore con il III *cardo* (Ruggiero 1885, 609-629). Le modalità di recupero, durante le operazioni di "abbassamento delle terre che coprono gli antichi monumenti", a circa 4,60 m di altezza dal piano di campagna, non lasciano dubbi sul fatto che i frammenti fossero stati trascinati fino a lì dopo il crollo della struttura sulla quale si trovava la quadriga.

Lo studio consente di abbandonare definitivamente le vecchie ipotesi che riconoscevano nel teatro o nello spazio interno alla Basilica Noniana il luogo di collocazione originaria del monumento e di accettare, invece, l'ipotesi più recente secondo cui la quadriga sarebbe stata posta sull'arco quadrifronte occidentale che insisteva sul *decumanus maximus*, in prossimità dell'ingresso alla Basilica Noniana (Allroggen Bedel 1974, 99-100; Esposito, Camardo 2013, 227-228). Parlano in favore di ciò anche i dati archeologici desumibili dalle indagini più recenti che hanno evidenziato in maniera netta l'avvenuto crollo dell'arco quadrifronte occidentale sulla facciata della Basilica Noniana, circostanza che spiega il ritrovamento dei frammenti sia all'interno che all'esterno dell'edificio e anche più a valle (Guidobaldi 2008; Esposito, Camardo 2013, 228). Altre ipotesi su un diverso collocamento della quadriga in un contesto monumentale posto più a monte, o nell'*Augusteum*, sembrano più difficili da sostenere, specie se si guarda alle modalità di sparpagliamento dei reperti.

3.2 *La documentazione materiale*

Grazie allo scavo documentario è stato possibile stilare un nuovo e più ricco elenco dei frammenti riconducibili al monumento, prima di procedere alla loro individuazione nei depositi del museo (specialmente l'ultima sala del "Deposito Affreschi" e "Sing Sing"). L'approccio integrato dei metodi della ricerca ha permesso di decretare l'estraneità o la pertinenza alla quadriga dei singoli reperti esaminati, costituendo la base metodologica su cui fondare una loro ricomposizione in scala reale, prima di procedere alla costruzione dell'ipotesi ricostruttiva generale. In pochi casi si è registrato un margine di dubbio che non ha permesso di attribuire, né di escludere i frammenti.

Per questi casi dubbi si potrà forse sciogliere la riserva solo dopo un supplemento di indagine che preveda anche l'impiego di differenti mezzi diagnostici, come l'XRF per l'analisi della composizione della lega o altra tecnologia a seconda dei casi (sull'impiego di strumenti diagnostici per lo studio di altre sculture bronzee di provenienza ercolanese: Lahusen, Formigli 2007; Pafumi 2020). Tali mezzi potranno essere utili anche per una valutazione successiva dei frammenti rimasti ai margini della discussione perché troppo piccoli o perché morfologicamente non significativi (perlopiù frammenti del corpo dei cavalli). Va tuttavia osservato che questo tipo di indagine supplementare potrebbe non essere sempre dirimente, dal momento che per un monumento di grande formato quale era la quadriga le partite di bronzo utilizzate nella fusione potevano differire in composizione a seconda delle parti e della resa che si voleva raggiungere (ad es. maggiore o minore resistenza al peso e alle sollecitazioni: Pafumi 2020, 70); inoltre, nella stessa area da cui proviene la quadriga è accertata l'esistenza di altre statue equestri, possibilmente riconducibili anche allo stesso ambiente di produzione.

Tra i reperti ammessi al programma di studio è stata quindi effettuata una selezione di circa 87 pezzi di varie dimensioni, molti dei quali inediti. Ne fanno parte: il cd. "Cavallo Mazzocchi" (inv. n. 4904) (Fig. 6), che rappresenta in questo studio una sorta di "elemento guida", nonostante le manipolazioni dei restauratori settecenteschi cui si deve, verso la metà del secolo, la sua ricomposizione in figura intera da un cavallo rinvenuto in stato frammentario nel 1739 (*Antichità Ercolanesi*, *De' Bronzi*, II, 255-256, tav. LXVI); frammenti anatomici diversi riconducibili agli altri cavalli di analogo modello che, simmetricamente disposti, a due a due, componevano il tiro a quattro; elementi strutturali – ruote e raggi, giogo, frammenti della cassa – ed elementi decorativi del carro – testata del timone, cornice del parapetto, cinque grandi *appliques* figurate poste a decorazione della cassa – (*Antichità Ercolanesi*, *De' Bronzi*, II, tavv. LXVII-LXIX; Kreilinger 1996, tav. 10).

A questo gruppo si deve aggiungere anche un nucleo di almeno dieci piccole *appliques* figurate che con ogni probabilità decoravano i baltei dei cavalli della quadriga componendo scene di lotta tra barbari e Romani (Cerulli Irelli 1972; Kreilinger 1996, tav. 10). Menzione a parte va fatta per i frammenti che ricompongono la figura umana in nudità eroica (parte sinistra del corpo, spalla e braccio destro, gluteo destro, gamba sinistra) già identificata da Gabrici con il personaggio celebrato e posto alla guida del carro (Gabrici 1907). La sua leggibilità complessiva si è adesso notevolmente accresciuta grazie alla possibilità di ricondurvi con certezza, avendone riconosciuto anche l'esatto punto di attacco, un bellissimo manto interamente decorato ad agemina con motivi di stelle, precedentemente ritrovato nei depositi del museo e identificato con uno dei frammenti recuperati nel 1762 (Pafumi 2020, 119-120, figg. V, 59-60). Alla stessa statua, infine, appartiene con ogni probabilità anche una gamba destra frammentaria rinvenuta nel 1932, rimasta a tutt'oggi nei depositi dell'*Antiquarium* di Ercolano (inv. n. 865).

Di tutti i frammenti riconosciuti come pertinenti alla quadriga e di tutti quelli che su base morfologica sono sembrati più utili ai fini della sua ricostruzione, sono stati effettuati la schedatura informatizzata, il rilievo fotografico e fotogrammetrico e la modellazione 3D. In parallelo è stato condotto un attento lavoro di ricognizione della documentazione iconografica antica e specialmente di quella pertinente al tema del trionfo, cui per molti aspetti si deve ricondurre la tipologia del gruppo monumentale indagato e parte del messaggio da esso veicolato. Nella nostra quadriga, però, sono presenti alcuni elementi – ad es. il grifo come testata del timone e il giogo con terminazioni in forma di crescente lunare – che rimandano ad una dimensione non solo eroica, ma anche "divinizzante". Tali elementi contribuiscono a spiegare gli scostamenti dall'iconografia canonica della quadriga trionfale anche per ciò che riguarda la scelta del tipo statuario in nudità eroica impiegato per la rappresentazione della figura, molto probabilmente Augusto *divus*, alla guida del carro.

Lo studio iconografico, condotto su una cospicua raccolta di documentazione archeologica del I-II sec. d.C., costituita da monete, rilievi, vasellame in argento, gemme, etc., non è stato solo metodologicamente imprescindibile, com'è ovvio nella ricerca archeologica, ma anche dirimente in molti casi per l'identificazione stessa dei reperti attribuibili al monumento ercolanese tra quelli esistenti nei depositi del Museo Archeologico Nazionale di Napoli. Basti per tutti l'esempio del frammento di cornice del parapetto del carro (Fig. 2) rinvenuto nel 1872, la cui decorazione ad ovoli e lancette trova confronti assai stringenti con quella del carro trionfale raffigurato su una tazza argentea rinvenuta a Boscoreale, oggi conservata al Louvre (inv. n. BJ2367) (Fig. 3). L'identificazione di questo pezzo è stata fondamentale per la ricostruzione

Fig. 2 – Frammento di cornice bronzea di carro con decorazione ad ovoli e lancette (codice reperto QERC_34).

Fig. 3 – Tazza di Boscoreale (Parigi, Museo del Louvre) di età tiberiana e dupondio di età caligolea (Berlino, Münzkabinett der Staatlichen Museen zu Berlin).

digitale della forma e delle dimensioni del carro, poiché restituisce un elemento morfologicamente significativo che, grazie alla curvatura, ne permette il completamento al di là di ogni dubbio sempre presente nelle ricostruzioni congetturali dell'archeologia.

Grazie ai dati raccolti sulla documentazione materiale e dallo studio condotto in parallelo sulla documentazione iconografica antica è stato possibile ipotizzare la forma complessiva del gruppo monumentale che può ricostruirsi con buona approssimazione grazie alle riproduzioni monetali della prima metà del I sec. d.C. e alla già citata tazza argentea di Boscoreale (Fig. 3). Su queste basi nessun dubbio può sussistere riguardo alla pertinenza delle cinque grandi *appliques* figurate alla decorazione del carro (inv. nn. 5004-5005, 5013, 5016, 109527+5360), sebbene più d'una potrebbero essere le ipotesi sulla disposizione, o meglio sull'ordine relativo, in cui esse debbano essere collocate sulla superficie della cassa e sulla loro interpretazione storico-artistica. Le valutazioni di carattere iconografico e stilistico, combinate con quelle di natura dimensionale, indirizzano verso nuove ipotesi rispetto a quella formulata dal Gabrici. Esse ruotano sull'identificazione di alcune delle figure con membri della famiglia giulio-claudia: un personaggio femminile *capite velato*, probabilmente Livia divinizzata nel 42 d.C. (inv. n. 5013), e due principi in *habitus* militare, forse Germanico e Druso Minore piuttosto che Caio e Lucio Cesare (inv. nn. 5004-5005).

Su questi e altri risultati della ricerca, che suggeriscono una collocazione cronologica del monumento in epoca claudia, molto probabilmente intorno alla metà del I sec. d.C., si troverà un approfondimento in prossime pubblicazioni specialmente dedicate agli aspetti interpretativi dello studio sulla quadriga.

S.P.

4. La gestione informatizzata dei dati della ricerca

La scelta di intraprendere percorsi di ricerca paralleli e complementari ha reso necessaria una riflessione sulle migliori strategie da adottare per la gestione dei dati scaturiti dalle indagini, in modo da non perdere informazioni utili alla ricomposizione del quadro storico-archeologico nel quale si colloca il monumento indagato. Pertanto, per la gestione dei dati storici si è proceduto alla realizzazione di una tabella informatizzata (Fig. 4) che permettesse la visione sinottica e diacronica delle informazioni desunte dalla lettura incrociata delle diverse fonti documentali, con il vantaggio di poter rileggere, in qualsiasi momento, i dati essenziali che fanno parte della storia del discoprimento dei diversi elementi ricondotti alla quadriga.

Per quanto riguarda, invece, la gestione dei dati "anagrafici" relativi alla documentazione materiale, si è proceduto alla realizzazione di una schedatura informatizzata dei reperti identificati scegliendo una delle trenta tipologie di schede di catalogo definite dall'Istituto Centrale per il Catalogo e la Documentazione (ICCD), la cui normativa è facilmente reperibile attraverso il website dell'Istituto (http://www.iccd.beniculturali.it/). A partire dalla scheda RA (Reperti Archeologici) si è proceduto con la selezione dei campi i cui dati si sarebbero posti come particolarmente rilevanti sia per l'individuazione univoca del manufatto, sia per agevolare una catalogazione futura, specialmente nei casi in cui essa risultava assente. Se per alcuni campi la scelta è stata obbligata – come, ad esempio, il "codice univoco", la "definizione" e la "categoria" – in altri casi è stato necessario operare una scelta di metodo. Nello specifico, per velocizzare le attività di recupero e di studio del reperto è stato indispensabile l'inserimento di una sezione in cui avere immediata contezza del luogo in cui questo sia conservato all'interno del MANN, considerata anche la presenza di svariati luoghi di immagazzinamento.

A ciò si aggiunge l'inserimento dei dati relativi alle caratteristiche e alle dimensioni fisiche del reperto attraverso cui si agevola l'interpretazione del

Data rinvenimento	Reperto	Informazioni di rinvenimento	Descrizione	Fonte	N° inv. MANN	Codice schedatura	Immagine di riferimento
13 luglio 1762	Panneggio con decorazione damaschinata	1. "casas lesionadas del cortile de Peruzo y Prior haciendo algunos pilares." 2. "Non molto lungi da d.antico Teatro ove si fanno de' pilastri per sostegno di alcuni bassi o diciam camare moderne lesionate per cagione di negligenza di chi prima teneva la direzione di quelli scavi."	1. "un pedazo grande de panichio de una estatua de metal de 3 pal. Y 2 on. largo y de 1 pal.de diam. a una punta y a la otra 6 on. y biene a ser el pedazo de manto que le caya à la estatua de sombre el ombro detras la espalda (in margine: Este panichio es una cosa particular por que es todo travajado como damasco...". 2.	1.min. Weber in Ruggiero 1885, pp. 388-389. 2. Nota di metalli et altre cose antiche che si trovano ne'Reali Scavamenti (Camillo Paderni), in Ruggiero 1885, p. 389.	Inventario Sangiorgio n. 4089	QERC_15	
3 giugno 1871	Testa bronzea di cavallo di grandezza naturale	"procedendo sempre all'abbassamento delle terre che coprono gli antichi monumenti ... perpendicolarmente alla strada, all'altezza di met. 4,60 dal lastricato."	"Bronzo. Una testa di cavallo di grandezza naturale mancante dell'orecchio sinistro e porzione della fronte e del collo. Gli occhi sono vuoti ed ha il morso alla bocca che è alquanto aperta e vi appariscono i denti. Un poco al di sopra della bocca vi sono due piccoli fori bislunghi per tenere la briglia. Lungo mt. 0,66. Pochi frammenti appartenenti alla testa suddetta."	Ruggiero 1885, p. 609.	115391	QERC_39	
9 giugno 1871	Ciuffo della testa del cavallo	"Il lavoro di cavamento proseguendosi come nei giorni precedenti, si è raccolto all'altezza di met. 4,60 dal lastricato."	"Un pezzo che comincia da sotto a cilindro forato, si eleva allargandosi a forma di pigna ed è sormontato da altro poco di cilindro che si ramifica in cinque corna, delle quali una che è verso il centro è piccolissima. Altezza maggiore met. 0,22."	Ruggiero 1885, p. 609.		[n.d.]	Nei depositi del MANN, ma attualmente risulta disperso
10 giugno 1871	Groppa di cavallo (fr.)	"Allo stesso livello di terra che si è lavorato la giornata di ieri."	"Bronzo. Un gran pezzo informe che potrebb'essere parte della groppa d'un cavallo, largo met. 0,62 per met. 0,82."	Ruggiero 1885, p. 609.		QERC_27	
14 giugno 1871	Gamba di cavallo	"Allo stesso livello dei terreni, cioè a met. 4,60 dal piano della strada si è rinvenuto, in bronzo."	"Una gamba destra di dietro d'un cavallo mancante di una porzione verso basso e del piede. La sua maggior lunghezza è met. 0,80."	Ruggiero 1885, p. 610.		QERC_29	

Fig. 4 – Visualizzazione parziale della tabella informatizzata per la gestione integrata dei record d'archivio e documentali.

frammento e, dunque, la ricomposizione del monumento. Poiché le campagne ricognitive, inoltre, hanno avuto luogo in tempi diversi e i frammenti recuperati e analizzati sono apparsi sin da subito particolarmente numerosi e vari nella forma e nelle caratteristiche, la scheda preliminare, nelle voci relative alla produzione grafica e al rilievo fotogrammetrico, è stata utile al fine di avere sempre chiaro il lavoro eseguito e da eseguire. La scheda, in definitiva, con tutte le informazioni in essa raccolte è stata realizzata in formato .PDF editabile (Fig. 5) con alcuni accorgimenti in grado di facilitare e velocizzare l'informatizzazione dei dati acquisiti. A questo proposito, infatti, sono state create caselle di controllo selezionabili per mezzo di spunta e menu a tendina per i campi caratterizzati da vocabolari.

Le riprese fotografiche per ciascun reperto sono state realizzate per mezzo di una Reflex Nikon D3000 e, seguendo i criteri specifici della fotografia dei reperti archeologici, ogni oggetto è stato fotografato secondo più prospettive, cercando di identificare gli elementi diagnostici e particolarmente caratteristici; è stato utilizzato uno sfondo neutro, con toni dal bianco al nero, e il riferimento metrico affiancato. Alla produzione *in loco* della documentazione fotografica dei reperti è seguita una fase di post-produzione in cui la fotografia del reperto è stata opportunamente modificata, scontornata eliminando lo sfondo e lasciando visibile solo l'oggetto e arricchita da riferimento metrico

Schedatura reperti nell'ambito del progetto
"La quadriga bronzea di Ercolano: studio, ricostruzione, valorizzazione"

Cd_reperto	QERC_01	**Dimensioni**	
Descrizione	Frammento bronzeo di cavallo	Larghezza (l): 27,5 cm	
Categoria	Scultura/Statuaria		
Datazione reperto (ca.)	non oltre il I sec. d.C.	Altezza (h): 20 cm	
Luogo conservazione	MANN - Deposito Sala affreschi		
Riferimenti presenti			
Anno rinvenimento		**Materiale**	
Luogo di rinvenimento	Ercolano	Metallo\Bronzo	
Note	Attualmente sito presso scaffalatura metallica		

Schizzo\Foto

Superficie poco deteriorata

Stato di conservazione

integro	parzial. ricomposto
intero	parzial. ricomponibile
mutilo	✘ frammentario
ricomposto	reintegrato
ricomponibile	parzial. reintegrato

Descrizione\Interpretazione

Frammento bronzeo di ventre di cavallo con parte di costato (?); visibile una leggera convessità; evidenti le fasce muscolari e le venature.

Fotografia
✘ Si — **Cd_foto** QERC_01_F1-F2
No

Rilievo fotogrammetrico
✘ Si
No

Operatore rilievo fotografico
Francesco Gabellone

Operatore schedatura
Fabiana Cerasa

Responsabile scientifico del progetto
Stefania Pafumi

Note

Data
06/07/2021

Fig. 5 – Esempio di scheda preliminare relativa al reperto QERC_01.

digitale. Le fotografie sono state rinominate con codice univoco e numero progressivo per reperto; codice che è stato poi inserito nell'apposito campo della scheda del pezzo.

Per gli oltre 87 frammenti censiti come afferenti alla quadriga di Ercolano, la schedatura così predisposta, corredata da documentazione fotografica, ha il pregio di consentire non solo l'identificazione univoca dei frammenti e una loro fruizione immediata, ma anche la gestione nel tempo delle informazioni ad essi pertinenti. Infine, essa costituisce un punto di partenza scalabile, implementabile, fruibile e condivisibile con altri specialisti.

F.C.

5. Lo studio morfologico-comparativo

5.1 *L'apporto dello studio tridimensionale per la ricostruzione*

Parallelamente al fondamentale studio storico-archeologico e ad una rilettura comparativa dei dati riferiti ai ritrovamenti, è stato effettuato un rilievo sistematico su base 3D dei frammenti, secondo uno schema preliminare volto alla verifica delle relazioni morfologiche tra gli elementi e ad una loro conseguente giustapposizione nello spazio tridimensionale. Tale verifica costituisce in sé una notevole risorsa di metodo, mai intentata in precedenza, poiché permette di esporre i reperti alla duplice verifica storico-archeologica e metrico-morfologica, secondo un approccio interdisciplinare indispensabile al riconoscimento delle congruenze, delle anomalie e dei possibili accostamenti (Gabellone 2019).

A tal fine sono stati esaminati dal punto di vista tridimensionale tutti i frammenti selezionati, in numero di circa 87, consistenti in elementi di piccole, medie e grandi dimensioni, dal "Cavallo Mazzocchi" (dimensioni circa 230×220 cm) ai frammenti di piccole *appliques* delle dimensioni di circa 7-10 cm. La maggior parte di questi oggetti, che non possono essere posizionati in modo da favorire un rilievo unitario, cioè con un unico passaggio, sono stati rilevati nella faccia anteriore e posteriore, con conseguente raddoppio dell'onere computazionale. Il rilievo è stato di tipo speditivo low-cost, con utilizzo della fotogrammetria digitale (Boccardo *et al.* 2001). La scelta del metodo di rilievo è stata condotta sulla base di alcune considerazioni tecniche e operative che si rapportano ai tempi necessari per la restituzione 3D e alle successive fasi di lavoro legate allo studio morfologico da remoto. Sebbene quindi il rilievo indiretto realizzato mediante scansione laser fornisca notoriamente maggiori garanzie di accuratezza metrica, le finalità del progetto hanno suggerito di usare la fotogrammetria digitale come principale metodo di studio e rilievo. Questa scelta si giustifica per diversi aspetti: la maggiore risoluzione e resa delle texture superficiali, la possibilità di "leggere" maggiori dettagli in relazione alla distanza delle prese fotografiche e al loro numero, la maggiore libertà nei rilievi di frammenti particolarmente difficili da riprendere con altri metodi (ad es. alcuni frammenti non facilmente movimentabili posti sul pavimento), la maggiore velocità di elaborazione in considerazione dell'elevato numero di frammenti da riprendere. Poiché la precisione e l'accuratezza del rilievo fotogrammetrico dipendono strettamente dalla capacità dell'operatore di "imbrigliare" il dato metrico con vincoli metrici e misurazioni dirette, si può affermare che il metodo fotogrammetrico, se correttamente eseguito, risulta rigoroso al pari delle altre misurazioni indirette attive (laser scanner).

Il dato metrico è stato pertanto costantemente confrontato con *constraints* collocati sul piano di rilievo. Le immagini sono state prodotte con fotocamera Fujifilm XT30 dotata di sensore da 26.1 megapixel X-Trans CMOS4 di quarta

Fig. 6 – Restituzione fotogrammetrica del cd. Cavallo Mazzocchi, Museo Archeologico Nazionale di Napoli.

generazione. Tale sensore ha permesso di ottenere modelli 3D con risoluzione mesh molto elevata. Il metodo di lavoro basato su fotogrammetria è risultato alla fine estremamente valido, con molte problematiche comuni anche ad altre tecniche di rilievo, ma con vantaggi importanti legati allo studio a distanza. Alcuni oggetti (assemblati poi nelle due facce) sono stati infatti depositati sulla piattaforma Sketchfab al fine di consentire la massima condivisione e lettura dei risultati 3D all'interno del gruppo di lavoro, anche in considerazione della contingente emergenza pandemica che ha impedito briefing in presenza.

La natura, molto scura e riflettente, delle superfici in bronzo ha comportato diverse difficoltà tecniche di rilievo, dovute alla scarsa ricchezza di dettaglio percepibile in foto e ai riflessi indotti dalla luce ambiente. La maggior parte degli oggetti è stata rilevata con risoluzione di circa 1.5-2 mm/mesh nelle aree più dettagliate, adeguata alle finalità del progetto (El-Hakim *et al.* 2003). Tale approccio, incrociato con lo studio archeologico, ha permesso di individuare l'estraneità di molti frammenti al gruppo della quadriga, consentendo altresì di rappresentare una ricomposizione in scala reale di quelli pertinenti e di procedere ad una prima ipotesi ricostruttiva. Questa prima selezione dei frammenti pertinenti risulta essere tra le operazioni più complesse dell'intero workflow, in quanto eventuali frammenti scartati potrebbero generare errori a catena anche sugli altri pezzi che potrebbero connettersi con questi.

Fig. 7 – Confronto tra visualizzazione con colore visibile e rappresentazione in phong shading. Nelle immagini a destra si possono osservare maggiori dettagli morfologici.

5.2 *La ricerca delle affinità morfologiche*

La ricerca delle affinità morfologiche dei molteplici frammenti di cavallo in studio e la loro collocazione e giustapposizione sono state determinate in relazione alla disponibilità del cd. Cavallo Mazzocchi (Fig. 6). In questo studio esso rappresenta l'elemento di comparazione principale per ogni determinazione di confronto stilistico; pertanto, dalla precisione della sua restituzione nello spazio 3D discendono gran parte delle osservazioni deduttive, basate sul metodo bottom-up. Il cavallo è stato perciò restituito con due metodi differenti. Il primo rilievo è stato eseguito con illuminazione diffusa, ma senza elementi di controllo. Tale metodo ha prodotto delle anomalie delle superfici e un errore residuale non accettabile (pari a circa 1 cm). È stato perciò utilizzato, successivamente, un secondo metodo di rilievo, con illuminazione più efficiente e con l'apposizione di piccoli target adesivi sulla superficie. Questo secondo metodo ha consentito di ottenere un modello 3D senza evidenti errori di orientamento della base fotografica e con risoluzione di circa 2 mm/mesh.

Come già detto, l'attendibilità metrica della restituzione del cavallo è determinante al fine di limitare al massimo gli errori di tolleranza che, come noto, caratterizzano tutti i rilievi a prescindere dal metodo usato. In questo studio 3D in particolare, il livello di tolleranza dipende anche da diversi altri fattori, estranei al rilievo, quali l'entità dei precedenti restauri, la disponibilità di frammenti con incrostazioni perché non ancora sottoposti a pulizia e restauro, nonché la loro possibile deformazione indotta dalla rottura dell'elemento integro. In considerazione di ciò si è quindi ritenuto di dover procedere con la massima precisione e cautela, compatibilmente con le tempistiche di lavoro determinate dall'imminente apertura dell'ala espositiva del museo (Campania romana) che accoglierà i primi risultati di questo studio. Dal punto di vista

Fig. 8 – Testa di cavallo (inv. n. 115391): malgrado la perfetta corrispondenza morfologica nella parte anteriore (a sinistra), il profilo del collo non corrisponde perfettamente con quello del Cavallo Mazzocchi (a destra). Le mancate aderenze morfologiche sono ascrivibili ai restauri effettuati sul frammento negli anni passati.

della leggibilità delle caratteristiche delle superfici, l'osservazione nello spazio tridimensionale ha permesso di riconoscere elementi plastici non immediatamente osservabili ad occhio nudo, ma estremante evidenti nell'osservazione in phong shading, una tecnica che può essere accostata all'osservazione a luce radente. L'immagine in Fig. 7 mostra le evidenti differenze tra la rappresentazione con colori reali e la rappresentazione in phong shading, che accentua le discontinuità superficiali, aiutando il riconoscimento delle analogie. In alcuni casi l'aderenza dei frammenti ad una parte anatomica del cavallo è molto alta, con muscolature e vasi sanguigni in evidente continuità con il modello di riferimento.

Per lo stesso motivo, alcuni frammenti sono invece stati classificati come "non pertinenti" perché, malgrado siano collocabili in modo abbastanza preciso sulle repliche digitali del Cavallo Mazzocchi, essi presentano delle differenze stilistiche evidenti, nella soluzione delle pieghe, nel diverso andamento delle muscolature, oppure nella mancata congruenza dimensionale. In altri casi alcuni frammenti di zampa sono stati esclusi perché la copertura degli arti era già completa e ciò dimostra che il tipo utilizzato per il Cavallo Mazzocchi potrebbe essere stato utilizzato anche per la produzione di altre statue equestri presenti nell'area di ritrovamento della quadriga. Tutte le analisi dimensionali e morfologiche sono sempre riferite a criteri di confronto operati all'interno di moderati fattori di tolleranza, verosimilmente dovuti a deformazioni nella rottura dei pezzi, ai piccoli "aggiustamenti" prodotti dai restauratori sul Cavallo Mazzocchi nei precedenti restauri, oppure alle probabili differenze esistenti tra copie provenienti dalla stessa matrice.

Fig. 9 – Evidenza di continuità anatomiche nel frammento rispetto al Cavallo Mazzocchi.

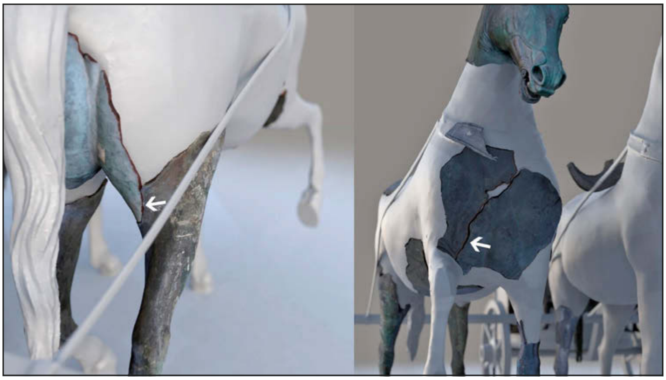

Fig. 10 – Esempio di matching morfologico con linee di frattura perfettamente corrispondenti.

Un evidente esempio di queste probabili differenze morfologiche è visibile nel confronto di un frammento di testa equina (inv. n. 115391), perfettamente sovrapponibile al modello, ma con molte differenze anatomiche nella curvatura del collo (Fig. 8). Ciò dipende in questo caso dagli interventi di restauro compiuti in tempi moderni. In altri casi, al contrario, sono state individuate perfettamente le corrispondenze delle linee di frattura e quelle di continuità anatomiche (vasi sanguigni, muscoli) che permettono di accostare alcuni frammenti con elevata precisione e attendibilità (Figg. 9-10).

La conformazione morfologica del carro e le sue dimensioni sono basate su alcuni elementi di raffronto già descritti in precedenza; tuttavia, è stato possibile ipotizzare l'andamento tridimensionale del profilo curvilineo della cassa anche grazie alla presenza di un frammento di cornice ad ovoli (Fig. 2) che ne caratterizza il perimetro superiore. La soluzione risulta ben accostabile alla rappresentazione presente sulla tazza di Boscoreale (Fig. 3). Le dimensioni in altezza della cassa sono infine desunte in rapporto alla dimensione delle ruote; infatti, la cassa appare spesso in misura confrontabile con le ruote del carro in gran parte delle rappresentazioni del periodo. Poiché la ricostruzione della ruota del carro è resa possibile, con ottima precisione, per il rinvenimento di 3/4 del suo perimetro, in base a questo metodo è possibile ricostruire con sufficiente approssimazione l'altezza della cassa.

Per ciò che attiene alle giustapposizioni possibili operate sulle figure umane prese in esame per l'identificazione del trionfatore, che comprendevano due personaggi togati e uno in nudità eroica, sono stati individuati specialmente per quest'ultimo nuovi elementi in connessione e corrispondenze dimensionali e stilistiche che permettono di riferire con certezza i frammenti esaminati alla stessa figura, ma non di dirimere la questione della sua attribuzione alla quadriga, che rimane quindi legata alle valutazioni di natura storico-archeologica.

5.3 *Il restauro virtuale come risorsa di metodo*

Il rilievo morfologico e il restauro virtuale della quadriga costituiscono, a livello metodologico, una forma di restauro guidato, vale a dire un criterio di verifica *ante rem* delle operazioni di intervento sui frammenti reali, che permette ai restauratori di conoscere in forma predittiva la collocazione dei frammenti stessi rispetto all'insieme. Questo consente di programmare le necessarie operazioni di movimentazione, per procedere all'eventuale restauro con notevole risparmio di tempo, disponendo di un riscontro digitale che semplifica in maniera significativa ogni fase di intervento reale. Le risorse tecnologiche, oggi disponibili anche in forma low-cost, costituiscono l'elemento di svolta in queste attività di ricerca. Esse permettono di determinare con un approccio numerico le peculiarità di ogni oggetto studiato e di muovere con facilità nello spazio virtuale oggetti di notevole dimensione, senza limiti di peso, gravità ed estensione (Gabellone 2015).

Malgrado l'indubbia validità e scientificità del metodo, va comunque precisato che il riconoscimento delle congruenze di forma e l'accostamento virtuale dei frammenti non costituiscono in sé verifica definitiva e certa della pertinenza dei pezzi alla quadriga di Ercolano. Per quanto riguarda ad esempio i cavalli, essi forniscono una valida risposta sulla loro pertinenza al tipo del Cavallo Mazzocchi. La soluzione a questo elemento di incertezza può essere trovata incrociando questi importanti risultati di coerenza morfologica e archeologica con le altre indagini archeologiche ed eventualmente con quelle diagnostiche, anch'esse importanti per stabilire una piena compatibilità dei diversi frammenti di metallo attribuiti alla quadriga.

F.G.

6. Conclusioni

La costituzione di un team che, per pregressa esperienza nei depositi del Museo Archeologico Nazionale di Napoli e conoscenza dei temi e delle pratiche della ricerca applicabili al monumento indagato, potesse dialogare efficacemente, anche da remoto, con le strutture del museo preposte alla conservazione e al restauro, si è rivelata condizione non solo utile per l'avvio delle operazioni, ma anche determinante nel prosieguo delle stesse, soprattutto in considerazione delle forti limitazioni sopraggiunte da marzo 2020 fino alla metà del 2022, a causa dello stato emergenziale provocato dalla pandemia da Covid 19. L'organizzazione del progetto in due fasi, una di carattere prevalentemente progettuale e l'altra strettamente operativa, con la programmazione serrata delle attività necessarie all'acquisizione digitale dei reperti per lo studio anche da remoto, ha ridotto notevolmente i tempi necessari allo svolgimento delle indagini *in situ*, ovvero nei depositi del museo. Ciò ha reso più sostenibile il progetto anche per quanto riguarda gli aspetti economici.

La grande mole di dati scaturita nelle diverse fasi di lavoro, la conduzione parallela delle attività di documentazione e studio, oltre alla necessità di ottimizzare tempi e risorse, hanno suggerito l'opportunità di procedere da subito ad una gestione informatizzata dei dati raccolti. Nell'elaborazione delle strategie più idonee per realizzarla, si è dato peso al potenziale da esse offerto in termini di rapidità di documentazione, agilità di consultazione e facilità di utilizzo ai fini della ricerca presente e futura sul monumento in esame. Il lavoro di analisi dei frammenti statuari ammessi al programma di studio e di restauro è stato condotto mettendo in atto sia un approccio di tipo tradizionale, basato sui metodi scientifici propri della ricerca archeologica e storico-artistica, sia percorsi innovativi di tipo tecnologico. Fra questi ultimi, il rilievo morfologico e il restauro virtuale con finalità conoscitiva meritano particolare attenzione perché costituiscono, a livello metodologico, delle risorse di notevole impatto che, se correttamente affiancate ai procedimenti più tradizionali della ricerca archeologica, permettono risultati altrimenti impensabili.

La proposta ricostruttiva digitale cui si è pervenuti (Fig. 11) si fonda sull'integrazione di tutte le informazioni indiziarie offerte dalla ricerca sulla documentazione iconografica antica, sulle fonti storiche e sull'evidenza archeologica. La sua verifica attraverso il restauro digitale permette di riconsegnare agli studiosi e al pubblico un monumento ancora fortemente lacunoso e non privo di criticità e punti d'ombra, ma sicuramente molto più leggibile e fruibile nei suoi aspetti tecnici, artistici, figurativi, storici. La proposta è da intendersi, tuttavia, come un primo livello di ricostruzione poiché è limitata agli elementi di cui è stato finora possibile accertare la pertinenza ed è condizionata dalla necessità di completare tutte le valutazioni relative alla statua del personaggio (Augusto *divus*?) posto alla guida del carro, allo stato attuale ancora in fase di restauro.

Fig. 11 – Proposta di ricostruzione della quadriga di Ercolano: in bianco gli elementi integrati.

Essa permette, tuttavia, di cogliere le caratteristiche peculiari e per molti versi composite del monumento ercolanese che molto probabilmente recepiva un modello urbano di quadriga trionfale, adattandolo alle esigenze celebrative del contesto di utilizzo locale. Tali caratteristiche, in unione con lo stile eclettico dell'apparato figurativo, ben si accordano con una datazione intorno alla metà del I secolo d.C.

In conclusione, crediamo che il metodo integrato applicato allo studio della quadriga di Ercolano del Museo Archeologico Nazionale di Napoli possa rappresentare una buona pratica esportabile ad altri progetti similari. Esso rappresenta una valida opportunità di analisi consentendo di esporre i reperti alla duplice verifica storico-archeologica e metrico-morfologica, secondo un approccio interdisciplinare che permette di indirizzare con successo le scelte interpretative e di limitare al massimo il ricorso ad altri mezzi diagnostici. Esso rappresenta, infine, una risorsa fondamentale per ottimizzare i tempi e i costi della ricerca, perché consente di verificare le ipotesi di lavoro in corso d'opera, cioè man mano che esse si presentano, e di trovare anche successivamente, attraverso la simulazione virtuale e l'interazione fra i ricercatori, eventuali punti deboli o, viceversa, punti di forza condivisibili nella ricostruzione archeologica. Questo facilita la decisione di proseguire un percorso di indagine o di abbandonarlo se infruttuoso e agevola la programmazione mirata delle operazioni di movimentazione necessarie per procedere al restauro materico dei frammenti in vista di un allestimento espositivo.

S.P., F.G.

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BIBLIOGRAFIA

Allroggen-Bedel A. 1974, *Das sogenannte Forum von Herculaneum und die borbonischen Grabungen von 1739*, «Cronache Ercolanesi», 4, 97-109.

Allroggen-Bedel A. 2008, *L'Augusteum; la Basilica Noniana*, in M.P. Guidobaldi (ed.), *Ercolano. Tre secoli di* scoperte, Catalogo della mostra, Napoli, Electa, 34-53.

Antichità Ercolanesi, Le Antichità di Ercolano esposte, 8 voll., Napoli, Regia Stamperia, 1757-1792.

Boccardo P., Dequal S., Lingua A., Rinaudo F. 2001, *True digital orthophoto for architectural and archaeological applications*, ISPRS Archives, XXXIV, 5/W1, 50-55.

Cerulli Irelli G. 1972, *Decorazioni di baltei dal foro di Ercolano*, «Cronache Ercolanesi», 2, 35-103.

Esposito D., Camardo D. 2013, *La "Basilica Noniana" di Ercolano*, «Mitteilungen des Deutschen Archäologischen Instituts, Römische Abteilung», 119, 221-258.

Gabellone F. 2015, *Digital technologies and communication: Prospects and expectations*, «Open Archaeology», 1, 1 (https://doi.10.1515/opar-20150005).

Gabellone F. 2019, *Archeologia virtuale. Teoria, tecniche e casi di studio*, Lecce, Edizioni Grifo.

Gabrici E. 1907, *La quadriga di Ercolano*, «Bollettino d'Arte», 1, 1-12.

Guidobaldi P. 2008, *Le ricerche archeologiche nell'area della Basilica Noniana (VII,16)*, in P.G. Guzzo, M.P. Guidobaldi (eds.), *Nuove ricerche archeologiche nell'aera vesuviana*, Roma, L'Erma di Bretschneider, 410-413.

El-Hakim S.F., Beraldin J.A., Blais F. 2003, *Critical factors and configurations for practical 3D image-based modeling*, in *6th Conference on 3D Measurement Techniques*, II, Zürich, ETH, 159-167.

Kreilinger U. 1996, *Römische Bronzeappliken. Historische Reliefs im kleinformat*, Heidelberg, Verlag Archäologie und Geschichte.

Lahusen G., Formigli E. 2007, *Grossbronzen aus Herculaneum und Pompeji. Statuen und Büsten von Herrschern und Bürgern*, Worms, Wernersche Verlagsgesellschaf.

Pafumi S. 2019, *Bronze horsemen of the Augustan age from Herculaneum. New information from a "museum retrieval" in the reserves of the Civic Museum of Catania*, «Herom, Journal on Hellenistic and Roman Material Culture», 8, 203-235.

Pafumi S. 2020, *Disiecta Membra. Frammenti di statuaria bronzea di età romana del Museo Civico di Catania*, Roma, L'Erma di Bretschneider.

Pagano M. 2005, *I primi anni degli scavi di Ercolano, Pompei e Stabiae. Raccolta e studio di documenti e disegni inediti*, Roma, L'Erma di Bretschneider.

Pannuti U. 1983, *Il Giornale degli Scavi di Ercolano (1738-1756)*, «Atti della Accademia nazionale dei Lincei. Classe di scienze morali, storiche e filologiche. Memorie», serie 8, 26, 143-410.

Parslow C.C. 1995, *Rediscovering Antiquity: Karl Weber and the Excavation of Herculaneum; Pompeii and Stabiae*, Cambridge, Cambridge University Press.

Ruggiero M. 1885, *Storia degli scavi di Ercolano ricomposta su documenti superstiti*, Napoli, Tipografia dell'Accademia Reale delle Scienze.

Wallace-Hadrill A. 2011, *Ercolano. Passato e futuro*, Roma, L'Erma di Bretschneider.

ABSTRACT

The bronze quadriga of the National Archaeological Museum of Naples, recovered in fragments at different times in the history of the Herculaneum excavations, represent a case study of interdisciplinary importance. Its reconstruction has never been attempted so far, due to the many factors of uncertainty that weigh on its knowledge. A new study, reconstruction and enhancement project was launched in 2020-2021 by the CNR-ISMed in cooperation with the National Archaeological Museum of Naples with the aim of producing new scientific knowledge and restoring the beauty and uniqueness of the recomposed original monument to public use. The interpretative problems related to the quadriga are numerous, complex and, concerning archaeology and its methods, they span from the study of sources and excavations records to in-depth knowledge of Roman statuary, casting techniques and the iconographic and stylistic characteristics of Roman bronzes. In this scenario, the application of methodologies and technologies combined with traditional investigations represents an innovative integrated method. Thanks to the digital verification of hypotheses, it can produce, on solid scientific bases, a virtual reconstruction of the investigated monument. This not only makes the costs for scientific research more sustainable, but enables restoration work to be directed by optimising time and resources.

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SUSTAINABILITY OF 3D HERITAGE DATA: LIFE CYCLE AND IMPACT

1. Introduction

Although sustainable 3D digital data management and sharing was recognized as an issue since the early stage of Digital Archaeology, it is now becoming increasingly consistent and broadly recognized (Koller *et al.* 2009; Thwaites 2013; Scopigno *et al.* 2017; Champion, Rahaman 2019; Garstki 2020). The exploit of 3D data creation in the last years has raised multiple questions on how to address delicate issues such as how to assess the impact of digital visualisations, shared metadata standards, data accessibility, maintenance, and obsolescence. On one side the large diffusion in the Cultural Heritage (CH) sector of tools, both hardware and software, for creating 3D content and sharing it on the web has been fostering a worldwide process of digitisation. On the other, the increased usage of such tools and techniques has raised multiple issues. Specifically, web browsing reveals an over-production, often reduplication, of unexploited digital data, in contrast to, ironically, a complete lack of key heritage datasets.

Such a phenomenon is particularly evident in the controversial and iconic case of the Nefertiti bust 3D model. The 3D model has been at the centre of an intense debate about open access and the rightful claim of imposing a copyright license on a copy of a heritage artefact which is already in the public domain. The debate was started by the legal dispute between Cosmo Wenman, a digital artist who asked the Neues Museum of Berlin for the 3D scan data of the bust, and the Prussian Cultural Heritage Foundation[1] (Pittman 2020). Currently, this represents possibly one of the most (over) shared digital heritage models and on Sketchfab alone already has more than fifteen identical versions uploaded by different authors[2].

If this example undoubtedly represents a major victory for the open access community, it also delineates a dualism: over-sharing as opposed to the lack of proper organised 3D documentation of most of the European archaeological sites, historical buildings, monuments, and museums' collections made accessible for research purposes.

[1] For further reading on the legal dispute please visit: https://reason.com/2019/11/13/a-german-museum-tried-to-hide-this-stunning-3d-scan-of-an-iconic-egyptian-artifact-today-you-can-see-it-for-the-first-time/, accessed on 20/06/2022. For the correspondence between the two parts: https://cosmowenman.files.wordpress.com/2019/10/20191029-cosmo-wenman-nefertiti-3d-scan-foia-effort.pdf, accessed on 20/06/2022.

[2] https://sketchfab.com/search?category=cultural-heritage-history&features=downloadable&q=nefertiti&type=models, accessed on 10/06/2022)

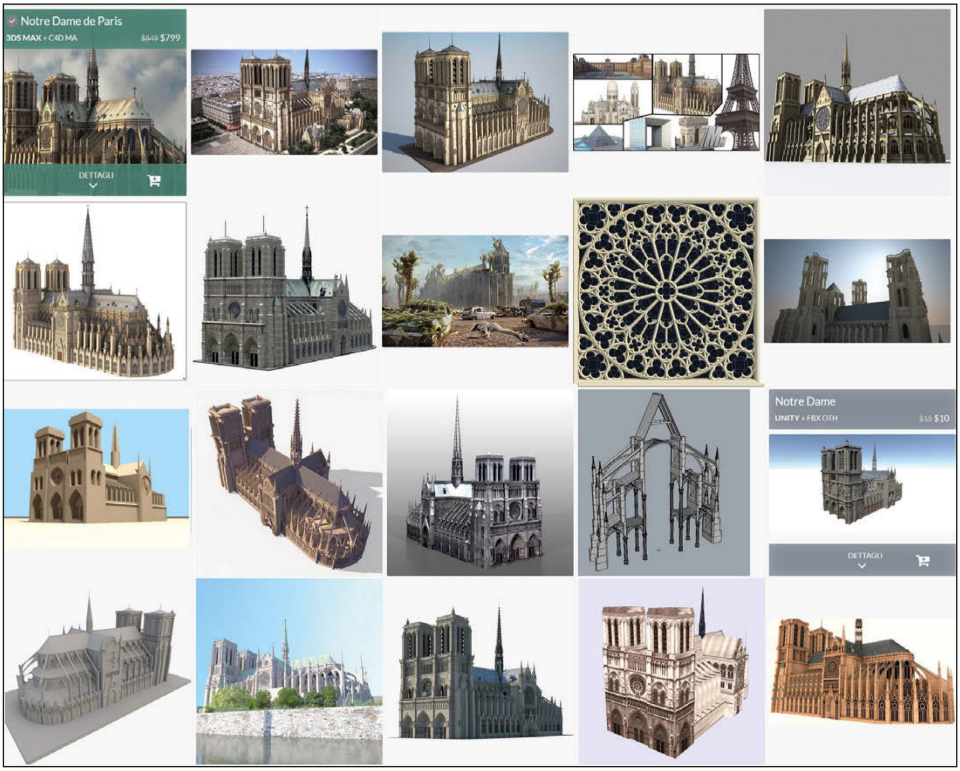

Fig. 1 – Image gallery of Notre Dame 3D models available online.

A dramatic example of the latter comes from recent history, and it is the Notre Dame cathedral in Paris. The whole structure apparently was 3D recorded after several laser scanning campaigns in 2011 and 2012 by an American Art professor from Vassar University, Andrew Tallon (Sandron, Tallon 2013; Tallon 2014). A series of dramatic events, such as the death of Dr Tallon in 2018 and the disaster that damaged the cathedral in 2019, combined with the fact that the 3D scans were «small enough to fit on a single hard drive, but unlikely to be stored in the cloud»[3] raised tangible concerns on how to retrieve the data from Tallon's hard disk and who should be the rightful owner of the 3D scans.

Luckily, in this case, Vassar University offered the data to help in the process of reconstruction and the ownership issues were temporarily solved. Currently, from a survey online it is possible to visualise some very low

[3] https://www.theatlantic.com/technology/archive/2019/04/laser-scans-could-help-rebuild-notre-dame-cathedral/587230/, accessed on 27/06/2022.

poly models of the cathedral made from photogrammetric elaborations of poor-quality footages. Alternatively, it is possible to buy a digitally made copy of the cathedral with a price range that goes from 8 dollars up to 800 (Fig. 1). There is no web trace of Tallon's raw 3D scans[4], and the risk of data loss remains still unsolved.

Are we, as researchers, really exploiting the possibilities offered by 3D data produced by other institutions or colleagues? Could we afford to adopt a 'digitise everything approach' without a proper strategy that involves how reducing environmental harm?

2. State of art and research questions

As recognised by Champion, Rahaman (2019), even though the European Union funded massive projects focused on infrastructure development (among them: Europeana, Ariadne, Ariadne Plus, Carare, 3D-ICONS; D'Andrea *et al.* 2012; Di Giulio *et al.* 2021), the possibilities offered by 3D data as scholarly resources are far from being fully exploited (Muenster 2022). The issue of a missing scholarly digital eco-system has been raised extensively and multiple times by, among others, Champion (Champion, Rahaman 2019, 2020). The web is nowadays the main channel for the dissemination of knowledge and emerging commercial solutions for web-publishing of 3D data are consolidating and becoming a de-facto standard for many applications. If indeed, there is an increasing diffusion of 3D recorded CH artefacts, sites and buildings, there is still very poor exploitation in terms of raw data web publication capabilities. As noted by R. Scopigno, there are numerous reasons possibly behind the lack of digital data sharing (Kuroczynski 2017; Scopigno *et al.* 2017) encompassing both geometry and color. What remains still an open problem is how to deliver those data and related knowledge to our society. The web is nowadays the main channel for the dissemination of knowledge. Emerging commercial solutions for web-publishing of 3D data are consolidating and becoming a de-facto standard for many applications (e-commerce, industrial products, education, etc., among which the most diffused causes are:

– Intellectual property rights issues.
– Fear of misuse (i.e., commercial use without authorisation) or use without proper citation.
– Fear of disclosing data part of ongoing or unpublished research.
– Lack of expertise or adequate financial support.

[4] https://shop.leica-geosystems.com/leica-blk/blog/precision-laser-scans-notre-dame-cathedral-can-help-preserve-restore-and-rebuild, accessed on 27/06/2022, the link to the scans' preview is unavailable).

Even though in recent years a huge effort has been invested in creating a shared set of paradata and metadata standards (Batini *et al.* 2009; Bentkowska-Kafel, Denard, Baker 2012; Hermon, Niccolucci, Ronzino 2012; Wilkinson *et al.* 2016; Aloia *et al.* 2017; Meghini *et al.* 2017; Gattiglia 2018; Richards 2021; Börjesson *et al.* 2022), there are growing concerns about how 3D data shared solely through web visualisation tools could contribute to a broader scientific debate. On the topic, Ekengren *et al.* (2021, 338) recently observed that: «Despite the multiple solutions offered by 3D visualisation technology and the different experiments carried out so far, it is still difficult to define the role and potential that 3D archives of archaeological artifacts have in producing new knowledge. So we may ask ourselves – are these 3D archives impacting higher education and research in a significant way, and what strategies and tools should we implement for transforming these instruments into assets capable of supporting multimodal engagement?».

Furthermore, there are other underestimated factors linked with digital heritage data sharing:

1) Archaeology as a discipline is mostly based on destructive research methods: the impossibility of accessing raw data of the 3D recordings of, for instance, an excavation not only inhibits scholars but also represents a tragic loss of irretrievable information. Replicability gives consistency to and is the base of a scientific approach. Although "Replicability" and "Archaeological research" look far from being linked, admittedly new advances in the Digital Archaeology methodology are going towards that direction (Frischer 2008; Demetrescu, Ferdani 2021; Dell'Unto, Landeschi 2022).

2) Data transparency against "digital faith". Compelling and aesthetically appealing digital visualisations could be deeply problematic or even misleading. A 3D model can have greater reach and impact than an academic paper but without appropriate supporting matter, transparent analysis, and citation of sources (Kuroczyński, Hauck, Dworak 2014), it offers nothing to advance rigorous scholarly debate (Frischer *et al.* 2002; Hermon, Niccolucci, D'Andrea 2005). These issues were raised alongside the well-known instances stated in the London and Seville Charters (Beacham, Denard, Niccolucci 2006; Bendicho, Lopez-Menchero 2013). In my opinion, this also applies to a certain extent to 3D models derived from a direct recording, especially when it comes to artefacts with some peculiarities or very small details that must be recorded. Accessing a final elaboration, without comparing it with raw data and paradata, could be as much misleading as a made-up reconstruction.

3) Digital data obsolescence. The UNESCO charter on the preservation of Digital Heritage in the section dedicated to "Guarding against loss of Heritage" recognizes hardware and software obsolescence as a major threat to digital data survival (Ioannides *et al.* 2012). A concern shared by, among

others, Harold Thwaites (2013, 340), who stated: «we cannot afford to have our digital heritage disappearing faster than the real heritage or the sites it seeks to 'preserve' otherwise all of our technological advances, creative interpretations, visualisations, and efforts will have been in vain». As Bernard Frischer (2005, 7) already noted, by neglecting to take measures against this risk we could very soon face a major problem called 'the death of the digit'.

4) Web platform ownership. Hosting 'sensible data' on a platform managed by a private company, that as such could, for instance, go bankrupt or decide to interrupt updates, is a major threat to data preservation.

5) Restrictions imposed by web visualisations. For most of the commercial and non-commercial platforms available online, web visualisations imply limits of file size uploads (Champion, Rahaman 2020; Fund, Schoueri, Scheibler 2021; *European Commission. Directorate General for Communications Networks, Content and Technology* 2022), therefore what is really accessible and can be visualised is a low-poly version of the original 3D model[5].

The theme of web visualisation limits must not be underestimated. Based on the ability of the 3D data producer, low-poly models could preserve a good level of texture detail through a process called 'baking'. Such a process could also be applied for normal and displacement maps to retrieve further information on some features of the scanned object, while the detail of the physical geometry of the 3D model is drastically reduced. The open question, again, is the same: is this enough to allow an independent researcher to grasp the complexity of, for instance, an artefact, a historical building, an archaeological site or even a single stratigraphic unit? Furthermore, in this scenario how quality standards could effectively counterbalance the file-sized related data loss?

When it comes to 3D data, defining quality standards is a very complicated challenge (*European Commission. Directorate General for Communications Networks, Content and Technology*, 2022), which involves the metadata schemas, architecture and standards as much as the tools used for recording a specific CH object typology (an archaeological site, a find and a monument, even though recorded through the same techniques or tools, require different approaches) up to the digital characteristics of the elaborated model (i.e., texture and mesh geometry).

An explicatory example of the impact of an unbalanced relationship between texture quality intended for web visualisation and physical geometry of the digital copy is the 3D model of the Rosetta Stone (Fig. 2), published in 2016 on Sketchfab by the British Museum[6]. The model in the texture visualisation mode appears rich in details, even though the texture quality

[5] An interesting exception is the 3DHOP tool. However, as a web visualiser it needs to be hosted on a proprietary server in order to work properly.

[6] https://sketchfab.com/3d-models/the-rosetta-stone-1e03509704a3490e99a173e53b93e282, accessed on 21/06/2022.

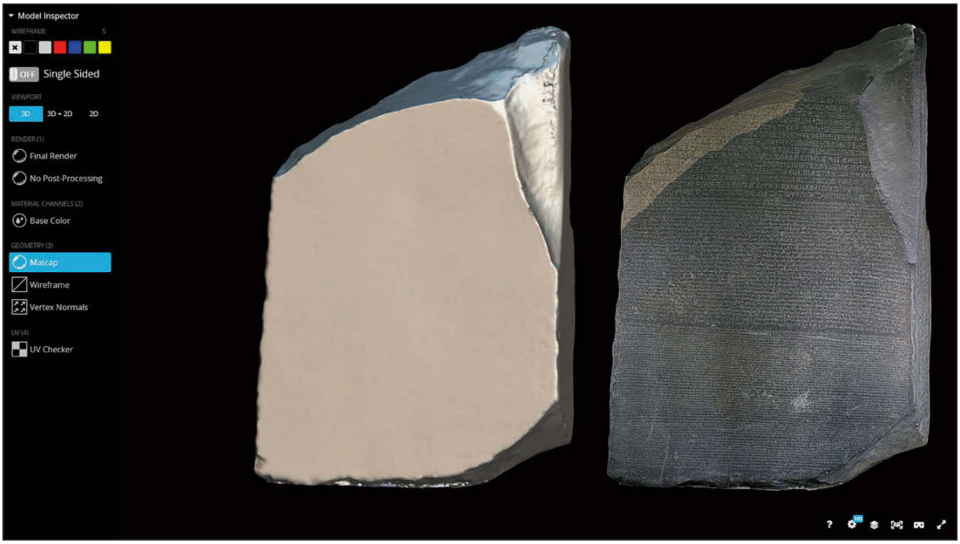

Fig. 2 – The Rosetta Stone 3D model from The British Museum Sketchfab page (left: ‘matcap’ visualisation mode, right: textured).

is reduced because of the web platform limits. Conversely, if we switch to ‘matcap’ visualisation in the model inspector panel, it shows a completely flat-surfaced geometry which did not record any of the ‘physical’ features of the signs left by the incisions on the stone. Therefore, the geometry definition level, under the texture, is mostly inadequate for research purposes.

The issue of inadequate research impacts is even more evident in the case of 3D recordings of large archaeological sites or historical buildings. Such 3D recording processes need substantial financial support, often granted from government funding or as part of a wider EU-funded project, to allow a team of trained specialists fully equipped to perform multiple campaigns of laser scanning acquisitions, alongside aerial and terrestrial photogrammetry. What happens afterwards with the colossal amount of raw data produced? How often do very large 3D scanning fieldwork campaigns, after having produced terabytes of point clouds, reach their peak remaining locked into local or private hard disks? The lack of proper data sharing inevitably leads to the fact that if another group of researchers wants to study the same area/monument, they will most likely need to go through two separate 3D scanning processes, doubling costs, time and resources for the same action. Not to mention that for a single scholar such a set of tasks could be far beyond the Herculean effort. We cannot afford the risk of considering these two processes, data over-reduplication and data hoarding, as two separate phenomena.

In the same way, such scenario raises an ethical dilemma: is it right that projects funded through community contributions do not share raw data with other specialists that could produce further knowledge or positive impacts on community-recognized heritage? How could this current data life cycle enhance research and cultural democracy? According to E. Kansa (2012, 507), «the discipline should not continue to tolerate the personal, self-aggrandising appropriation of CH that comes with data hoarding'; indeed, data withholding represents a clear threat to preserving the archaeological record» and could also lead to the dangerous '*campanilismo* effect' described by B. Frischer (2005, 4).

The pattern highlighted so far already shows signs of long-term unsustainability, even without considering the impact of digital data on the environment in terms of energy consumption. As already reported by Jones and Champion (Jones 2018; Champion, Rahaman 2019), even though currently the consumption of data centres is just 1% of the global electricity demand, the fast growth of this sector makes the future difficult to foresee: «Already, data centres use an estimated 200-terawatt hour (TWh) each year. That is more than the national energy consumption of some countries, including Iran, but half of the electricity used for transport worldwide, and just 1% of global electricity demand. Data centres contribute around 0.3% to overall carbon emissions, whereas the information and communications technology (ICT) ecosystem as a whole – under a sweeping definition that encompasses personal digital devices, mobile-phone networks and televisions – accounts for more than 2% of global emissions. That puts ICT's carbon footprint on a par with the aviation industry's emissions from fuel. What could happen in the future is hard to forecast. But one of the most worrying models predicts that electricity use by ICT could exceed 20% of the global total» (Jones 2018, 163).

We are past beyond the zettabyte (10^{21} bytes) era (IEA 2017), experiencing an explosion in terms of data production and Internet connections, under the risk of heavily impacting natural resources and the environment (Jones 2018; Champion, Rahaman 2019; Potts 2021). Even though one of the side effects of the pandemic crisis was a general reduction of energy consumption (IEA 2021), global electricity demand exponentially grew by 6% in 2021. It represented the largest-ever annual increase in absolute terms and the largest percentage rise since 2010 (IEA 2022). Moreover, we cannot underestimate costs and consumptions in terms of energy and limited natural resources used as components in hardware and data centres' construction and their subsequent disposal.

The above concerns instigated retroinspection of the EU-funded project concerning CH digitisation in the past years. The European Commission funded at least 110 projects that produced or involve 3D heritage data. Conversely, only a few of them released the raw data, concretely contributing to an independent scientific debate. It is worth noticing that, in the new funding scheme Horizon Europe, the European Commission is increasingly relying on Open Science, Data Sharing and Open Access. For instance, by including Open Science practices in the Excellence section of the project or by requesting a data management plan where data sharing should follow the principle "as open as possible, as closed as necessary" and be in line with the FAIR principles. Nevertheless, how have digital heritage projects been acting so far?

Moreover, this research points to underline the importance of an existing web tool, such as Zenodo, towards a more sustainable approach to 3D datasets. Zenodo is an online repository, launched by OpenAire and CERN in 2013, now hosted at CERN and already in use by scholars from all fields of science. The repository was specifically designed to help researchers from smaller institutions to share results in a wide variety of formats, allowing them to upload raw data and publications secured by a DOI number (Sicilia, García-Barriocanal, Sánchez-Alonso 2017).

This research argues that at present, in this historical period, this borderline situation represents the right moment to go through a methodological discussion on what must be digitised, how to preserve the recorded data and, above all, why is it fundamental to maximize the impact of heavy 3D data sets, fully exploiting their potential to foster hyper-disciplinary research. Re-thinking the life cycle of 3D datasets is at this point a mandatory task in order to modify an alarming trend.

3. Materials and method

The analysis started from an online survey of the Community Research and Development Information Service (CORDIS) website. CORDIS hosts info, objectives, and results from all the projects funded by the EU's framework programmes for research and innovation and the platform is managed by the Publications Office of the European Union (https://cordis.europa.eu/about/en). The survey focused on the EU-funded projects that explored heritage and produced 3D data, either as a final output or as a starting point for a broader process. Therefore, as a first step, a filtered selection of all the projects was made through the search tool available on the website, using two main strings of words: "3D heritage" and "laser scanning digitisation heritage". The search resulted in 188 projects selected in total between the two combined textual strings (https://cordis.europa.eu/search/en, accessed on 05/01/2023).

All the datasets were downloadable and offer a rich set of information about each project. Hence, as a second step, the filtered results were downloaded as an Excel sheet, and the attention was drawn to three main elements:

1) if there was any reference to 3D data sharing, accessibility or sustainable management in the project's short description and objective on CORDIS;

2) if the 3D datasets produced during the project were made available for download and not just uploaded for web-based visualisations;
3) if the external link to the project's website, usually available on CORDIS, was present and still active. This third element, apparently less significant, is a key indicator of how the concept of digital sustainability was approached. Maintenance cost and content creation are two factors usually underestimated but they are the two main elements against content fragmentation or loss.

The third step involved an analytical review of the full datasets implementing the recording scheme of the downloaded Excel sheet with 3 new columns for the 3 factors previously explained. For each project, the information reported was checked, both on the database and on CORDIS, and the new data were filled in. Of the 188 projects initially filtered, 110 (58%) were really pertinent to the Heritage and 3D data production topic (Fig. 3) because of directly approaching or mentioning it. While the 78 labelled as 'non-relevant' (41%) were a heterogeneous group of projects which were neither connected to the CH sector nor openly stating on CORDIS any kind of interest in 3D data production (even though some did) or 3D data sharing.

4. Results

From the 188 initially filtered projects from CORDIS, a final group of 110 relevant projects was selected because they directly or indirectly produced 3D heritage data. Among these only 35 explicitly mentioned data sharing on the project's resumé on CORDIS, accounting for 31% of the relevant projects.

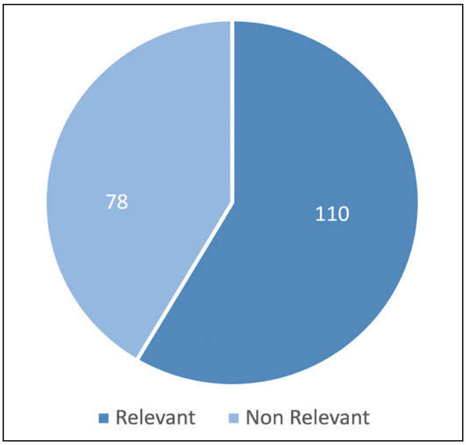

Fig. 3 – Chart that shows Relevant and Non-Relevant projects filtered from the research.

Furthermore, an in-depth analysis revealed that 8 out of 110 projects (7%) provided downloadable 3D data but not necessarily the raw data. In only one case there was specific mention that the 3D models production started from already existing datasets. If the projects classified as relevant but without an explicit reference to 3D data sharing are taken into account, the percentage slightly decreases to 6% (12 out of 188).

Just 3 of the 8 projects made the data accessible to all without constrictions. The other 5 showed different levels of restrictions, such as quantity or limited access to the platform for the download (Fig. 4). The usage of Zenodo for sharing a 3D point-cloud registration is recorded only for a project with a 2023 end date. Fig. 5 shows how the distribution of projects involving 3D heritage data has changed in recent years. It reveals a very positive trend that reached a quantitative peak in 2018-2022 with 13 projects. It is difficult to foresee but looking at the data collected so far, the trend should maintain its positive growth. It is also worth noticing that from the 188 projects analysed, 96 maintained an active link directed to a website, which accounts for roughly 51% of the total amount (Fig. 6). Even if, among these, 9 links redirected to a non-dedicated or official project web page (i.e., Facebook or ResearchGate pages) or the website of an institution which did not report direct mentions about the relative project (i.e., University's homepage).

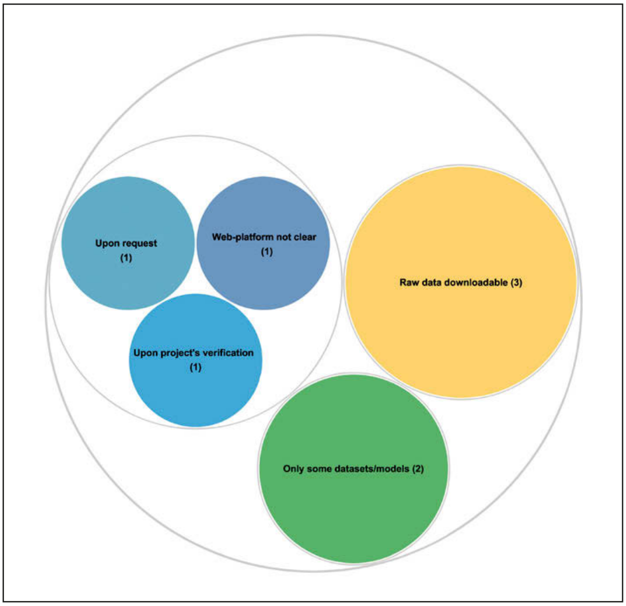

Fig. 4 – Chart that shows levels of access restriction to 3D data download.

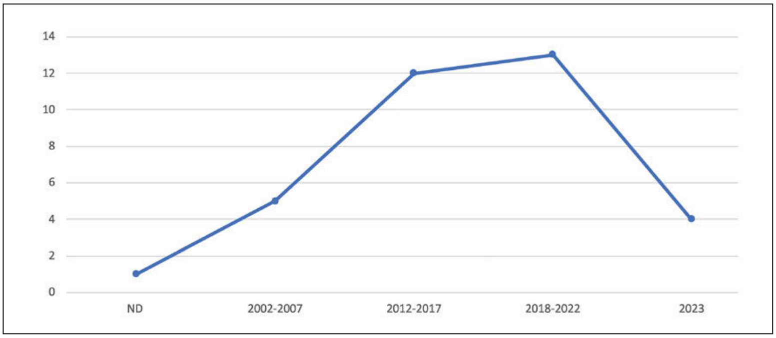

Fig. 5 – Graph that shows the trend of projects approaching 3D heritage data production and data sharing.

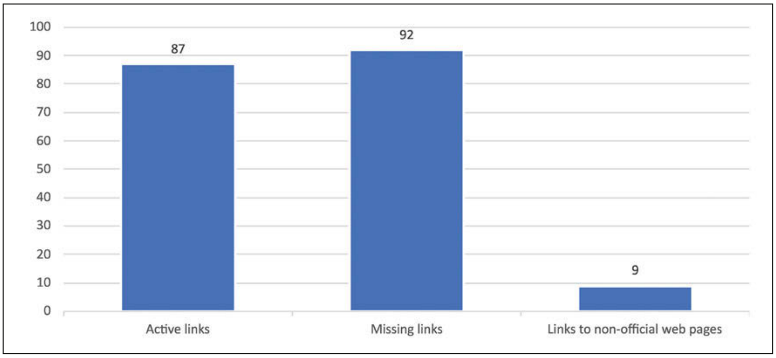

Fig. 6 – Chart that shows the proportion between projects with an active weblink and projects without.

5. Discussion

Starting from a general overview of some of the long-standing problems that have been affecting Digital Archaeology in the last 20 years, this paper wants to openly address some of these criticalities by looking at how certain alarming trends are currently affecting our approach to Digital and Digitised Heritage at European level. The analysis corroborates the idea that a generalised lack of 3D raw data management plans is forcing an unsustainable approach to heritage digitisation processes.

The data collected reveals a discontinuous trend which appears unsatisfying if compared with the number of EU-funded projects that produced 3D datasets. It is evident a lack in terms of 3D data sharing whereas only 8 projects out of 110 have concretely released some of the datasets produced. Another evident trend that points to sustainability issues is websites statistics: only 51% of the total projects, 96 out of 188, have maintained an active weblink on CORDIS. These patterns underline two different but entangled issues of digital obsolescence, and they both represent a threat to sustainability and preservation of our Digital Heritage. On one side there is an under-exploitation of datasets produced through community funding which will inevitably lead to one of the scenarios described in the introduction; on the other, the risk of web disappearance is a tangible threat. The lack of projects' web footprints represents a loss for the whole community. While the latter is a concern less related to the main goal of this paper, the statistics derived from data sharing are more alarming when it comes to Digital Heritage and research purposes.

It is indeed promising to notice that an ongoing project has already uploaded through Zenodo some of the raw data produced. However, it is undoubtedly mandatory to re-think the way in which, as European community, we approach the preservation of our Digital Heritage as much as the documentation of our physical heritage. It is true that the solution offered by Zenodo at European level is something that has been theorised and abundantly proposed by several scholars (Benardou *et al.* 2018) and is already in use by some EU-funded projects, mainly through a group created on the platform by OpenAIRE called European Commission Funded Research. Nevertheless, the lack of usage among Digital Heritage projects is evident. An example of how Zenodo could foster a more sustainable approach to 3D data is the project e-Archeo (https://e-archeo.it/, accessed on 02/01/2023). The project strongly relies on Zenodo to involve and create a dialogue among scholars through 3D models. Among the datasets available, point clouds, photogrammetry projects, orthophoto (Soriano 2022) and plans, are easily accessible as much as reconstructive 3D models (Bellelli *et al.* 2022).

Each dataset has a versioning Digital Object Identifier (DOI): this solution allows reproductions, updates, as much 'reversibility', data validation and citation (Koller *et al.* 2009). Therefore, this system could strongly rely on community-led quality control: the more a dataset is used the more it is analysed by the scientific community, and the more it becomes reliable. Re-use is a crucial step towards digital sustainability. A sustainable approach to CH digitisation should be based on both data selection and digital continuity, those are two recognised key factors to approach the issues of maintenance and obsolescence. Data selection implies a clearly defined set of selection principles, which are still an open question. Nevertheless, the value of the content and its potential high significance for future researchers should be prioritising factors. Another key aspect is represented by digital continuity: it is undisputable the need to allow access to digital content that «may, for much of its life, be changing, and that change itself is a necessary part of that maintenance process» (Bradley 2007, 161). Survival against obsolescence is not granted, but the more a dataset is accessed and used the more the chances are that it could be updated at two different levels:

1) At a quantity level, with newly collected raw data. This, on one hand, implies a growth of the dataset's file size, but, on the other, also of the detail and quality of information and transformations that occurred to the subject documented. An example could be again the Notre Dame cathedral: combining Tallon's point clouds with 3D scans recorded after the fire would be undoubtedly a fundamental dataset enrichment.
2) At a usability level, in terms of data format and/or software version. As software and data formats change continuously and at different speeds, re-usability allows files to be constantly updated from and for the community.

This could lead to a form of data sets' 'self-maintenance', where the broad scientific community' responsibilities towards 3D data are clearly defined and mainly based on providing reliability and update through active usage based on a DOI versioning system. The more the scientific community grows the more the whole system is able to sustain itself. Among the side effects that such a system would have are data transparency issues. Reliability and transparency are two strictly entangled concepts. Once the entire process of digital production is replicable because it is possible to deconstruct and re-construct each step, then there will be the premises to counterbalance 'digital faith': that instinctive reaction of trustworthiness that a Digital Heritage model, as a product of highly specialised computer graphic elaborations, often generates. Combined these two factors, re-usability and transparency, could drastically change the currently unsustainable digital life cycle, they could even become a research booster. The possibility to assign a DOI to a dataset, and consequently to create a direct link between data, author, dataset transformations and hypotheses or reconstructions, is not fully exploited so far. It could be a huge advantage for public institutions, such as museums or archaeological sites, to have the data protected with scientific attribution but still accessible to researchers and in the position to stimulate new projects' ideas. Data accessibility is the key against 'digital faith'.

This approach is being adopted by the whole Extended Matrix Initiative (Demetrescu, Ferdani 2021), working on developing an open source tool that has the potential to bridge the gap between physical and hypothetical. The EM tool is currently the solution that is closer to answer to some of the London Charter's instances and is doing so paradoxically by reversing the canonical usage of 3D models: turning 3D data into a step of a broader heuristic process and not as a final product, using 3D visualisations to display and link hypotheses, reasonings and sources. In short, thinking differently about 3D data as a dynamic resource for the community. "Visualisations as provocations" as Haynes proposed. On the topic, the approach applied by the ERC-funded project Rome Transformed appears very promising. By re-adapting a web platform developed by Dr Marc Grellert (http://sciedoc.org/, accessed on 30/03/2023), they are working on connecting and making reconstructive renders, digital visualisations and underpinning sources open to the public (Haynes *et al*. 2021). By doing so on a multi-layered and challenging case study, such as the eastern Celian area in Rome, they have the potential to impact the broader scientific community, empowering researchers and fostering new researches.

The cases presented so far show how processes of availability and transparency of sources are leading towards a necessary shift. A methodological shift, that is directing the focus on considering 3D models as raw data more than a finished product. Such a process must start, at least at the European level, from community-funded projects. Those are the role models: as projects that obtained major funding, they have the possibility to define a new trend in terms of outputs and methodological approaches, which, ideally, will then be reused by other research institutions and re-adapted by private companies and turned into industry standards. This must include a specific digitisation strategy with a clearly defined methodology and objectives.

The need to plan in advance and decide why we need to produce 3D data and how to share them is fundamental for turning the whole process into a sustainable practice, while considering digitisation as both the project starting point and its end result will inevitably lead us to be possessed by the tools and not in control of the workflow. Even though it refers to quality standards in thematic analysis applied in psychology, the methodological warning expressed by V. Braun, V. Clarke (2020, 2) is very relevant. The balance between adopting methodological standards and succumbing to proceduralism or 'methodolatry' must be found in «understanding what the procedures are, what they give you access to, and that these are tools for a process, rather than the purpose of analysis, is important».

6. Conclusion

The positive impacts that CH could have on communities' well-being through the promotion of a shared cultural identity and a broader sense of belonging is openly recognised in the European Green Deal. Furthermore, in the same document, the role of Digital Heritage is viewed as central to creating an inter-generational connection that could foster memory preservation and social inclusion. Therefore, as clearly stated in the ICOMOS Green Paper, the heritage digitisation program is considered in the upcoming future as a key step towards sustainable development. However, in the same Green Paper, the authors express sincere concern about the carbon emissions produced by large-scale ICT activities. If there is not a sustainable approach underpinning this heritage digitisation shift, how could digitised heritage generate a positive cycle?

From this point of view, it is very accurate how Dr Isabel Rimanoczy (2021, 10) approached the definition of sustainable activities, clearly stating that the concept of 'sustainability' should not be confused with just re-thinking pollution and waste policies. Alongside actions towards harm reduction, a sustainable approach must also focus on producing positive impacts. The Sustainability Mindset is defined as «a way of thinking and being that results from a broad understanding of the ecosystem's manifestations, from social sensitivity, as well as an introspective focus on one's personal values and higher self, and finds its expression in actions for the greater good of the whole» (Kassel *et al.* 2018, 7). Therefore, in approaching heritage digitisation we should look at the broader scenario and point to the greater good, at least at the European level as a starting point, developing and sharing a common strategy.

The Italian *Piano Nazionale di Digitalizzazione del patrimonio culturale* (PND) is an embryonic example of a necessary initiative at a national level, which at the same time must be actively linked to wider European digitisation-level standards. This is particularly felt at the paradata level, where the lack of shared standards could be very problematic in the future. Cases like, for example, objects digitised through 3D scanners develop high risks of data obsolescence due to the fact that each 3D scanner has its own property software and data format. Therefore, data maintenance and data survival are at high risk of becoming obsolescent in the medium-long term future.

Equally important to reducing harm is the generation of positive impacts: to do so it is fundamental to fully exploit the power of 3D data in connecting, as a bridge, researchers and specialists from different fields, fostering hyper-disciplinary projects. How much a vast restoration program of a historical building, could benefit from previously recorded 3D data, ideally produced by another research project conducted by architects or archaeologists? What if the same datasets, with minor updates, could allow structural engineers to perform structural viability analysis? In such a context, the benefits and the outputs derived from the multiple re-uses of the same dataset balance the costs of production, storage and maintenance.

As Digital Archaeologists we should look beyond the mere data production and the exercise in the style of choosing a certain tool or software. This is something that Jeremy Hugget (2015, 84) powerfully summarised by saying: «Digital Archaeology should be a means of rethinking archaeology, rather than simply a series of methodologies and techniques».

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REFERENCES

Aloia N., Binding C., Cuy S., Doerr M., Fanini B., Felicetti A., Fihn J. *et al.* 2017, *Enabling European archaeological research: The ARIADNE e-infrastructure*, «Internet Archaeology», 43 (https://doi.org/10.11141/ia.43.11).

Batini C., Cappiello C., Francalanci C., Maurino A. 2009, *Methodologies for data quality assessment and improvement*, «ACM Computing Surveys», 41, 3, 1-52 (https://doi.org/10.1145/1541880.1541883).

Beacham R., Denard H., Niccolucci F. *et al.* 2006, *An introduction to the London charter*, Joint Event CIPA/VAST/EG/EuroMed 1, 1.6.

Bellelli V., Pietroni E., Rizzo C., Carlani R., Palermo A., Rosati F., Dettori M., Bucci V., Monotti G. 2022, *Cerveteri, Tomba dei Capitelli. Dataset ricostruzione virtuale, back-end scientifico, storytelling*, Zenodo (https://doi.org/10.5281/ZENODO.6614066).

Benardou A., Champion E., Dallas C., Hughes L.M. (eds.) 2018, *Cultural Heritage Infrastructures in Digital Humanities*, London-New York, Routledge, Taylor & Francis Group.

Bendicho V., López-Menchero M. 2013, *International guidelines for Virtual Archaeology: The Seville Principles*, in C. Corsi, B. Slapšak, F. Vermeulen (eds.), *Good Practice in Archaeological Diagnostics*, Natural Science in Archaeology, Cham, Springer International Publishing, 269-283 (https://doi.org/10.1007/978-3-319-01784-6_16).

Bentkowska-Kafel A., Denard H., Baker D. (eds.) 2012, *Paradata and Transparency in Virtual Heritage* (*Digital Research in the Arts and Humanities*), Farnham, Surrey, England-Burlington, VT, Ashgate.

Börjesson L., Sköld O., Friberg Z., Löwenborg D., Pálsson G., Huvila I. 2022, *Re-purposing Excavation database content as paradata: An explorative analysis of paradata identification challenges and opportunities*, «KULA: Knowledge Creation, Dissemination, and Preservation Studies» 6, 3, 1-18 (https://doi.org/10.18357/kula.221).

Bradley K. 2007, *Defining digital sustainability*, «Library Trends», 56, 1, 148-163 (https://doi.org/10.1353/lib.2007.0044).

Braun V., Clarke V. 2020, *One size fits all? What counts as quality practice in (reflexive) thematic analysis?*, «Qualitative Research in Psychology», 18, 3, 328-352 (https://doi.org/10.1080/14780887.2020.1769238).

Cappellini V. (ed.) 2012, *Electronic Imaging & the Visual Arts: EVA 2012 (Florence 2012)*, Firenze, University Press.

Champion E., Rahaman H. 2019, *3D Digital Heritage models as sustainable scholarly resources*, «Sustainability», 11, 8, 2425 (https://doi.org/10.3390/su11082425).

Champion E., Rahaman H. 2020, *Survey of 3D Digital Heritage repositories and platforms*, «Virtual Archaeology Review», 11, 23, 1 (https://doi.org/10.4995/var.2020.13226).

D'Andrea A., Niccolucci F., Bassett S., Fernie K. 2012, *3D-ICONS: World Heritage sites for Europeana: Making complex 3D models available to everyone*, in *2012 18th International Conference on Virtual Systems and Multimedia*, Milan, IEEE, 517-520 (https://doi.org/10.1109/VSMM.2012.6365966).

Dell'Unto N., Landeschi G. 2022, *Archaeological 3D GIS*, London, Routledge (https://doi.org/10.4324/9781003034131).

Demetrescu E., Ferdani D. 2021, *From field archaeology to virtual reconstruction: A five steps method using the Extended Matrix*, «Applied Sciences», 11, 11, 5206 (https://doi.org/10.3390/app11115206).

Di Giulio R., Boeri A., Longo D., Gianfrate V., Boulanger S.O.M., Mariotti C. 2021, *ICTs for accessing, understanding and safeguarding Cultural Heritage: The experience of INCEPTION and ROCK H2020 Projects*, «International Journal of Architectural Heritage», 15, 6, 825-843 (https://doi.org/10.1080/15583058.2019.1690075).

Ekengren F., Callieri M., Dininno D., Berggren Å., Macheridis S., Dell'Unto N. 2021, *Dynamic collections: A 3D web infrastructure for artifact engagement*, «Open Archaeology», 7, 1, 337-352 (https://doi.org/10.1515/opar-2020-0139).

European Commission. Directorate General for Communications Networks, Content and Technology 2022, *Study on Quality in 3D Digitisation of Tangible Cultural Heritage: Mapping Parameters, Formats, Standards, Benchmarks, Methodologies, and Guidelines: Final Study Report*, LU, Publications Office (https://data.europa.eu/doi/10.2759/471776).

Frischer B. 2005, *New directions for cultural Virtual Reality: A global strategy for archiving serving and exhibiting 3D computer model of Cultural Heritage sites*, in R. Vergnieux, C. Delevoie (eds.), *Actes du Colloque Virtual Retrospect 2005*, Archéovision 2, Bordeaux, Ausonius, 168-175.

Frischer B. 2008, *From digital illustration to digital heuristics*, in B. Frischer, A. Dakouri-Hild (eds.), *Beyond Illustration: 2D and 3D Digital Technologies as Tools for Discovery in Archaeology*, BAR International Series 1805, Oxford, Archaeopress, V-XXIV.

Frischer B., Niccolucci F., Ryan N.S., Barceló J.A. 2002, *From CVR to CVRO: The past, present, and future of cultural Virtual Reality*, in F. Niccolucci (ed.), *Virtual Archaeology between Scientific Research and Territorial Marketing. Proceedings of the VAST EuroConference (Arezzo 2000)*, BAR International Series 1075, Oxford, Archaeopress, 7-18.

Fund N., Schoueri K., Scheibler C. 2021, *Pure 3D: Technical Report*, Maastricht University (https://pure3d.eu/wpcontent/uploads).

Garstki K. 2020, *Digital Innovations in European Archaeology*, Cambridge, Cambridge University Press (https://doi.org/10.1017/9781108881425).

Gattiglia G. 2018, *La maternità e la paternità del dato archeologico. L'esempio del MOD (Mappa Open Data)*, in M. Arizza, V. Boi, A. Caravale, A. Palombini, A. Piergrossi (eds.), *I dati archeologici. Accessibilità, proprietà, disseminazione (Roma 2017)*, «Archeologia e Calcolatori», 29, 51-58 (https://doi.org/10.19282/ac.29.2018.06).

Haynes I., Liverani P., Carboni F., Ravasi T., Kay S., Piro S., Morelli G. 2021, *Rome transformed: Interdisciplinary analysis of the Eastern Caelian (Rome)*, «Papers of the British School at Rome», 89, 342-346 (https://doi.org/10.1017/S0068246221000088).

Hermon S., Niccolucci F., D'Andrea A. 2005, S*ome evaluations on the potential impact of virtual reality on the archaeological scientific research*, in H. Thwaites (ed.), *VSMM2005. Proceedings of the Eleventh International Conference on Virtual Systems and Multimedia. Virtual Reality at Work in the 21st Century. Impact on Society*, Budapest, Archaeolingua, 1-9.

Hermon S., Niccolucci F., Ronzino P. 2012, *A metadata schema for Cultural Heritage documentation*, in V. Cappellini (ed.), *Electronic Imaging & the Visual Arts: EVA 2012 (Florence 2012)*, Firenze, Firenze University Press (https://doi.org/10.1400/187333, accessed on January 9, 2023), 36-41.

Huggett J. 2015, *Challenging digital archaeology*, «Open Archaeology», 1, 1 (https://doi.org/10.1515/opar-2015-0003).

Ioannides M., Fritsch D., Leissner J., Davies R., Remondino F., Caffo R. (eds.) 2012, *Progress in Cultural Heritage Preservation: 4th International Conference, EuroMed 2012 (Limassol, Cyprus 2012)*, vol. 7616, Lecture Notes in Computer Science, Berlin-Heidelberg, Springer (https://doi.org/10.1007/978-3-642-34234-9).

Jones N. 2018, *How to stop data centres from gobbling up the world's electricity*, «Nature», 561 (7722), 163-166 (https://doi.org/10.1038/d41586-018-06610-y).

Kansa E. 2012, *Openness and archaeology's information ecosystem*, «World Archaeology», 44, 4, 498-520 (https://doi.org/10.1080/00438243.2012.737575).

Kassel K., Rimanoczy I., Mitchell S.F. 2018, *A sustainability mindset model for management education*, in K. Kassel, I. Rimanoczy (eds.), *Developing a sustainability mindset in management education*, London, Routledge, 3-37.

Koller D., Frischer B., Humphreys G. 2009, *Research challenges for digital archives of 3D Cultural Heritage models*, «Journal on Computing and Cultural Heritage», 2, 3, 1-17 (https://doi.org/10.1145/1658346.1658347).

Kuroczyński P. 2017, *Virtual research environment for digital 3D reconstructions. Standards, thresholds and prospects*, «Studies in Digital Heritage», 1, 2, 456-476 (https://doi.org/10.14434/sdh.v1i2.23330).

Kuroczyński P., Hauck B.O., Dworak D. 2014, *Digital reconstruction of Cultural Heritage. Questions of documentation and visualisation standards for 3D content*, in *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation and Protection, 5th International Conference, EuroMed (Limassol, Cyprus 2014)*.

Meghini C., Scopigno R., Richards J., Wright H., Geser G., Cuy S., Fihn J. *et al.* 2017, *ARIADNE: A research infrastructure for archaeology*, «Journal on Computing and Cultural Heritage», 10, 3, 1-27 (https://doi.org/10.1145/3064527).

Muenster S. 2022, *Digital 3D technologies for Humanities research and education: An overview*, «Applied Sciences», 12, 5, 2426 (https://doi.org/10.3390/app12052426).

Pittman L.D. 2020, *Combatting copyright overreach: Keeping 3D representations of Cultural Heritage in the public domain*, «New York University Law Review», 95, 1192.

Potts A. 2021, *European Cultural Heritage Green Paper "Putting Europe's Shared Heritage at the Heart of the European Green Deal"*, Europa Nostra, The Hague & Brussel.

Richards J.D. 2021, *Archiving archaeological data in the United Kingdom*, «Internet Archaeology», 58 (https://doi.org/10.11141/ia.58.21).

Rimanoczy I. 2021, *The Sustainability Mindset Principles: A Guide to Develop a Mindset for a Better World*, The Principles for Responsible Management Education Series, London-New York, Routledge.

Sandron D., Tallon A. 2013, *Notre-Dame de Paris: neuf siècles d'histoire*, Paris, Parigramme.

Scopigno R., Callieri M., Dellepiane M., Ponchio F., Potenziani M. 2017, *Delivering and using 3D models on the web: Are we ready?*, «Virtual Archaeology Review», 8, 17, 1 (https://doi.org/10.4995/var.2017.6405).

Sicilia M.-A., García-Barriocanal E., Sánchez-Alonso S. 2017, *Community curation in open dataset repositories: Insights from Zenodo*, «Procedia Computer Science», 106, 54-60 (https://doi.org/10.1016/j.procs.2017.03.009).

Soriano F. 2022, *Desenzano, Villa romana, Rilievo fotogrammetrico*, Zenodo (https://doi.org/10.5281/ZENODO.6007431).

Tallon A. 2014, *Divining proportions in the information age*, «Architectural Histories», 2, 1, 15 (https://doi.org/10.5334/ah.bo).

Thwaites H. 2013, *Digital Heritage: What happens when we digitize everything?*, in E. Ch'ng, V. Gaffney, H. Chapman (eds.), *Visual Heritage in the Digital Age*, Springer Series on Cultural Computing, London, Springer, 327-348 (https://doi.org/10.1007/978-1-4471-5535-5_17).

Wilkinson M.D., Dumontier M., Aalbersberg I.J., Appleton G., Axton M., Baak A., Blomberg N. *et al.* 2016, *The FAIR Guiding Principles for Scientific Data Management and Stewardship*, «Scientific Data» 3, 1, 160018 (https://doi.org/10.1038/sdata.2016.18).

ABSTRACT

In recent years, the exploit of 3D data use in Archaeology and the Cultural Heritage sector in general has caused an exponential multiplication of digital content that can be viewed on the web. Nevertheless, web platforms can display a concerning dualism: on one side some contents are over-represented with the same models uploaded dozens of times even inside the same platform; on the other, the inaccessibility or absence of proper 3D documentation for certain datasets limits the usefulness of the resources. As a result of substantial funding received (mostly from public institutions) and the volume of data produced by each digitization project, the final impacts on the broader scientific community remain limited. Starting from the analysis of data published about EU-funded projects by the European Union Commission on the platform CORDIS, this research approaches the delicate issue of the unsustainability of the current 3D data life cycle. The analysis of 110 selected projects revealed a disturbing pattern: even though the EU provided funds for many projects that approached in different ways 3D data diffusion or sharing, currently only 8 of them made the data accessible.

RECENSIONI

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F. Ciotti (ed.), *Digital Humanities. Metodi, strumenti, saperi*, Roma, Carocci Editore, 2023.

Era il 1992 quando veniva pubblicato il volume *Calcolatori e Scienze Umane. Archeologia e Arte, Storia e Scienze Giuridiche e Sociali, Linguistica, Letteratura* (Milano, ETAS Libri), come esito del Convegno organizzato dall'Accademia Nazionale dei Lincei e dalla Fondazione IBM Italia. Tito Orlandi, nella sua introduzione dal titolo "Informatica umanistica: realizzazioni e prospettive", oltre ad offrire un quadro dettagliato delle Associazioni, dei Centri, delle riviste specializzate e dei settori applicativi, poneva l'accento non solo sui problemi di carattere teorico connessi alla rappresentazione formalizzata delle informazioni, ma anche su quelli operativi, perché «il lavoro di chi applica l'informatica alle discipline umanistiche è soprattutto di tipo sperimentale». Così Orlandi indicava nella scelta e nello sviluppo di software interattivi, di linguaggi di marcatura e di un'organizzazione integrata del lavoro in un ambiente uniforme la strada più opportuna per favorire la crescita e la corretta applicazione dell'informatica nell'ambito delle discipline umanistiche.

A trent'anni dall'uscita di quel volume è stato stampato per i tipi dell'Editore Carocci il libro *Digital Humanities. Metodi, strumenti, saperi*, a cura di Fabio Ciotti, dedicato alla memoria di Dino Buzzetti, scomparso nell'aprile 2023, proprio mentre si procedeva all'invio alle stampe del volume. A Buzzetti si deve la prefazione al volume (*Prefazione. Oltre il limite istituzionale*, pp. 15-15), in cui lo studioso si sofferma sul progresso degli studi di informatica umanistica in Italia, fortemente caratterizzato oggi «dall'irruzione del nuovo concetto di Digital Humanities, sempre più contrapposto, anche esplicitamente a quello originario di Humanities Computing».

A Tito Orlandi, insieme a Francesca Tomasi, viene demandato il compito di illustrare la *Storia dell'informatica umanistica in Italia* (pp. 35-47), che vede dagli anni Novanta il prevalere degli aspetti tecnologici da un lato e la funzione trainante del web dall'altro. Il 2000 segna un momento di cesura con il passato attraverso quello «shift, che è tanto terminologico quanto concettuale, dalla Humanities Computing alle Digital Humanities», in cui la computazione torna ad essere una priorità e la rappresentazione digitale uno strumento di comunicazione dei risultati della ricerca. Il cambiamento decisivo si avverte però soprattutto nell'ultimo decennio, quando alle attività in locale si sostituisce il cloud, quando i dati si trasformano in Big Data e quando si assiste alla rinascita dell'Intelligenza Artificiale grazie agli sviluppi delle tecniche di Machine Learning. Le previsioni di Orlandi del 1992, dunque, non erano poi così lontane dalla realtà nell'indicare che sarebbero stati proprio i linguaggi e l'ambiente di lavoro a guidare gli sviluppi futuri.

Prima di passare all'analisi della struttura e dei contenuti del volume, va ricordato in questa sezione introduttiva il dotto intervento del curatore Fabio Ciotti (*Introduzione. La galassia delle Digital Humanities*, pp. 19-34) che affronta innanzitutto la questione terminologica, evidenziando come il termine anglofono Digital Humanities sia quello più adatto a definire un settore complesso e di natura interdisciplinare, in continua evoluzione ed espansione e con un'ampia varietà di approcci. La comunità scientifica che si interessa di Digital Humanities è oggi divenuta ampia e diversificata e il termine "galassia" utilizzato da Ciotti risulta un'efficace metafora astronomica che descrive questo campo del sapere come un disco galattico caratterizzato da un nucleo, cioè un ambito di ricerca autonomo dai caratteri transdisciplinari, da una parte interna in cui sono presenti bracci di spirale formati da stelle giovani (le singole discipline di recente formazione, dalla linguistica computazionale all'informatica archeologica) e da un profilo esterno, che consente alla galassia di entrare in contatto sia con le discipline umanistiche tradizionali sia con altre galassie disciplinari, in una sfera spazio temporale che determina l'interdisciplinarità della ricerca.

La struttura "astronomica" descritta nelle pagine introduttive si riflette anche nell'impostazione del volume, che è diviso nelle due parti dedicate a "Metodi, strumenti e infrastrutture" e "Campi e saperi", corrispondenti, nell'idea del curatore «al nucleo e al disco descritti sopra, con alcune licenze». La prima parte si apre con un intervento focalizzato sulla nozione di modello e modellizzazione, aspetto centrale della riflessione metodologica nelle Digital Humanities (*Modelli, metamodelli e modellizzazione nelle Digital Humanities*, di A. Ciula e C. Marras, pp. 51-65), a cui seguono alcuni capitoli incentrati sui testi, «i principali oggetti… e i principali strumenti di studio di buona parte delle discipline umanistiche», con particolare riguardo alla modellizzazione e codifica tramite linguaggi e framework (*La codifica del testo, xml e la tei*, di A. Ciotti, pp. 66-90), ai metodi di analisi quantitativa, con riferimento specifico al Machine Learning e alla Data Science (*L'analisi del testo*, di A. Ciotti, pp. 91-113), e alle edizioni scientifiche digitali (*Critica testuale e nuovi metodi: l'edizione scientifica digitale*, di E. Pierazzo e R. Rosselli Del Turco, pp. 114-136). Segue una trattazione che riguarda più specificatamente il settore dei beni culturali, in relazione al Semantic Web e ai Linked Data

(*Semantic Web, Linked Data e beni culturali*, di F. Tomasi e F. Vitali, pp. 137-159), sulla base dell'esperienza relativa alla collezione di Federico Zeri, ricca di quasi 400 epigrafi romane, una biblioteca d'arte e una fototeca. Il Semantic Web offre modelli e strumenti per creare rappresentazioni digitali avanzate di conoscenze specifiche, che in questo caso sono quelle relative ai beni culturali nelle collezioni, utili a superare i limiti degli schemi rigidi e a consentire una descrizione completa del bene stesso e di tutte le entità e i concetti ad esso collegati. Il nesso tra dati provenienti da fonti diverse è oggi possibile attraverso i Linked Open Data che, mediante la combinazione di informazioni eterogenee, consentono la creazione di reti di dati e infrastrutture concettuali sempre più complesse.

Dopo un capitolo sulla linguistica computazionale e il Natural Language Processing (*Trattamento automatico del linguaggio e Digital Humanities: metodi e strumenti, sfide*, di S. Montemagni, pp. 160-177), vengono poste al centro della trattazione le biblioteche digitali (*Biblioteche digitali: nascita, evoluzione, futuro*, di M. Agosti, pp. 178-196), le infrastrutture di ricerca sviluppate dall'Unione Europea, come CLARIN e DARIAH, nel loro ruolo di promotori di collaborazione e innovazione tecnologica (*Infrastrutture digitali per le scienze umane e sociali*, di M. Monachini e F. Frontini, pp. 197-213), nonché l'ecosistema dell'editoria scientifica digitale, con l'Open Access e l'Open Science, esaminati in riferimento a due progetti, le banche dati PubMed e Medrxiv (*Cultura open e cittadinanza scientifica*, di P. Castellucci, pp. 214-225). La cultura open è considerata una condizione fondamentale per un dialogo consapevole riguardo al diritto all'accesso all'informazione e alla conoscenza; essa non è solo un'ideologia isolata o una reazione contro il mercato, ma una risposta politica e scientifica ai bisogni profondi della società e delle comunità di ricerca.

La Parte Seconda contiene contributi che riflettono in particolare la specificità italiana, esplorando settori disciplinari con una forte tradizione di studi ed evidenziando risultati di eccellenza e sinergie in ambiti oggi in rapida espansione. Gli argomenti trattati considerano il rapporto con il digitale di alcune importanti discipline, anche nel loro percorso storico: la storia (*Storia digitale e Digital Public History: le novità di un antico mestiere*, di M. Ravveduto e E. Salvatori, pp. 229-254); la geografia (*Geografie digitali*, di R. Sprugnoli e T. Tambassi, pp. 255-266); la musicologia (*Musicologia digitale e spartiti digitali*, di R. Viglianti, pp. 267-281); l'archeologia (*L'informatica archeologica nell'era postdigitale*, di P. Moscati, pp. 282-298); la storia dell'arte (*La storia dell'arte e il digitale*, di A. Sbrilli, pp. 299-311); gli studi classici greci e latini (*L'antichità greco-romana e le tecnologie digitali*, di M. Berti, pp. 312-324); la filosofia (*Filosofia digitale? Orizzonti disciplinari*, di C. Marras, pp. 325-336); l'epigrafia (*L'epigrafia di fronte alla sfida del digitale*, di S. Orlandi, pp. 337-350).

In particolare, il capitolo dedicato all'informatica archeologica esamina questa disciplina nata negli anni Cinquanta del Novecento, che si è posta come fertile connubio di umanesimo, scienza e tecnologie, assumendo nel tempo un ruolo cruciale nella ricerca e gestione del patrimonio e contribuendo anche alla trasmissione efficace delle conoscenze sulle civiltà del passato. Il termine "Digital Archaeology" è oggi forse quello più adatto ad indicare questo ambito, che vede nel processo di digitalizzazione dei dati la fase fondante di ogni momento della ricerca e nelle infrastrutture di ricerca dedicate all'Heritage Science l'ambiente ideale per la consultazione e la conservazione delle informazioni. Anche l'epigrafia antica, al centro del saggio di S. Orlandi, è una disciplina che ha una lunga storia di progetti digitali; una disciplina che continua anche oggi nella sfida di sfruttare le grandi potenzialità offerte dalle tecnologie senza venir meno ai suoi caratteri fondamentali, finalizzati alla ricostruzione culturale e storica dei contesti antichi.

Con la ricchezza delle tematiche affrontate, il volume offre una mappa articolata delle possibilità illimitate che la transizione digitale offre agli studi umanistici e incoraggia a cogliere le opportunità offerte dalle tecnologie per affermare la centralità di un sapere in grado di affrontare le sfide attuali e contribuire alle prospettive future.

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N. Dell'Unto, G. Landeschi, *Archaeological 3D GIS*, London & New York, Routledge, 2022.

Il volume di Nicolò Dell'Unto e Giacomo Landeschi è pubblicato dalla casa editrice Routledge e prevede anche una versione open access con licenza CC BY-NC-ND 4.0 sul sito dell'editore (https://doi.org/10.4324/9781003034131). Il libro, arricchito da figure a colori di ottima qualità, si configura come un punto di riferimento fondamentale sugli sviluppi futuri dell'uso del GIS in ambito archeologico, grazie alla novità e alla profondità dei temi trattati e ad alcune oculate scelte editoriali, come quella di non ambire ad essere un tradizionale manuale universitario o un compendio tecnico-pratico o una raccolta di casi studio, ma di recuperare elementi chiave da ciascuno di questi "generi editoriali" per arrivare ad un pubblico di studiosi eterogeneo.

La Prefazione (pp. xvi-xvii), ad opera di Gary Lock, mette a fuoco l'importanza del volume nell'affrontare sistematicamente le innovative opportunità offerte dalla possibilità di lavorare con dati 3D in ambiente GIS. Un approccio che permette di approdare allo sviluppo di sistemi che integrano l'uso dei GIS, tipici della landscape e della field archaeology, con quello dei modelli 3D e della realtà virtuale, appannaggio della Virtual Archaeology; due discipline troppo frequentemente caratterizzate da sviluppi paralleli e indipendenti. Nella Premessa (p. xviii), ad opera degli stessi autori, si dichiara infatti come l'obiettivo del libro sia quello di stimolare la riflessione sulle opportunità di rappresentazione e analisi geospaziale delle informazioni 3D.

Il successivo capitolo di Introduzione (pp. 1-4) presenta la struttura del volume e le strategie di utilizzo suggerite. Il libro offre uno sguardo sui differenti metodi per risolvere i vari problemi che si possono presentare nello studio dello spazio tridimensionale, fornendo una descrizione dettagliata delle metodologie di ricerca. L'opera non costituisce dunque, a detta degli stessi autori, un manuale tecnico, ma un riferimento metodologico ricco di casi studio – alcuni più noti, come Pompei e Çatalhöyük, altri meno famosi, come i diversi siti preistorici e protostorici della Scandinavia meridionale – e soluzioni a problematiche archeologiche indagabili attraverso strumenti GIS 3D, ovvero piattaforme in grado di collezionare, visualizzare, comparare ed effettuare analisi geospaziali su dati tridimensionali e non. L'aspetto tecnico-pratico non viene comunque trascurato, ma limitato a specifici "informative box" che approfondiscono alcuni degli aspetti tecnici descritti. La scelta si rivela efficace sul piano della comunicazione in quanto permette un uso diversificato dello strumento a seconda delle necessità del lettore e del suo grado di esperienza. Il dettaglio e la chiarezza con cui vengono illustrati i diversi passaggi necessari al raggiungimento del risultato, in uno rapporto bilanciato tra stimoli suscitati e strumenti forniti, invogliano il lettore a replicare i medesimi flussi di lavoro nei propri progetti.

Così i primi due capitoli costituiscono le necessarie cornici teoriche e metodologiche dello sviluppo dei sistemi GIS e della modellazione 3D in archeologia. Si tratta di due sezioni importanti per fornire un'introduzione a chi si approccia per la prima volta a questi temi, di cui viene proposta una efficace e aggiornata sistematizzazione conoscitiva. Il Capitolo 1 (*Geographical Information System in archaeology*, pp. 5-17) si pone l'obiettivo di definire il ruolo del GIS in archeologia con particolare attenzione all'analisi spaziale e ai metodi quantitativi, mentre il Capitolo 2 (*3D models and knowledge production*, pp. 18-28) si concentra sulle rappresentazioni e sui modelli 3D.

Il Capitolo 3 (*3D GIS in archaeology*, pp. 29-54) confronta tra loro diversi tipi di piattaforme GIS 3D, mettendole in rapporto ad altre forme di visualizzazione e gestione dei dati 3D oggi in uso (BIM e Game-based visualizazion platforms). Inoltre, vengono forniti alcuni utili suggerimenti sulla strutturazione dei dati in un GIS 3D, assieme ad una utile panoramica delle varie forme di rappresentazione dei dati tridimensionali (§3.2 *Boundary, surface and volume 3D representations*, pp. 37-43). Da un punto di vista metodologico, un maggiore approfondimento sui sistemi BIM poteva essere auspicabile in questa sezione, soprattutto se considerati nel rapporto con i sistemi GIS in esame. Questo avrebbe consentito di delineare gli specifici campi di applicabilità ed evidenziare le profonde differenze che separano questi due sistemi. La trattazione avrebbe necessariamente occupato un certo spazio, costringendo gli autori ad allontanarsi dal tema principale, ma avrebbe fornito risposte ad alcune domande che possono sorgere nel corso della lettura: quando preferire uno dei due sistemi? Quando integrarli in ragione della loro possibile interoperabilità? Un aspetto, quest'ultimo, su cui le grandi casi produttrici di software (soprattutto Autodesk ed ESRI) stanno ultimamente investendo molte risorse.

Il Capitolo 4 (*Deploying 3D GIS at the trowel's edge*, pp. 55-82) illustra diversi esempi riguardanti l'uso di GIS 3D a supporto delle indagini sul campo, fornendo utili indicazioni e strategie per la gestione degli stessi sul cantiere, attraverso i casi di studio multidisciplinari di Çatalhöyük (Turchia), Kämpinge e Sandby borg (Svezia). Si tratta evidentemente di contesti archeologici tra loro molto diversi sia per cronologia sia per ambito culturale, ma questo contribuisce a dimostrare la versatilità dello strumento informatico adottato. Il Capitolo 5 (*Surface and subsurface analysis*, pp. 83-95) esplora le potenzialità del GIS 3D per analizzare dati derivati da nuvole di punti al fine di valutare lo stato di conservazione delle superfici, se colpite da danni antropici, come nel caso del villaggio vichingo di Öppenskär (Svezia), o dal degrado ambientale, come nel caso di Pompei (Italia).

Il Capitolo 6 (*3D visibility analysis*, pp. 96-108) discute l'impatto del GIS 3D sugli studi di visibilità per mezzo dell'analisi LOS (line of sight), utilizzata per misurare interrelazioni visuali dirette tra un punto di osservazione (A) e un oggetto (B) all'interno di uno spazio 3D. Nel caso studio che accompagna il capitolo, quello della *domus* di Cecilio Giocondo a Pompei, questo tipo di analisi viene applicato per ricostruire il diverso grado di visibilità di due distinte scene pittoriche all'interno della casa. Il capitolo 7 (*Volumes*, pp. 109-124) introduce e discute le tecniche di visualizzazione e analisi volumetrica; il caso della grotta di Stora Förvar (Svezia) offre la possibilità di esaminare le potenzialità di questo strumento. La ricostruzione delle informazioni volumetriche del deposito archeologico sulla base delle informazioni d'archivio, assieme alla loro rappresentazione in uno spazio tridimensionale, permette agli studiosi di valutare la distribuzione spaziale delle classi di manufatti rinvenuti, giungendo così alla costruzione di nuovi modelli interpretativi per il contesto. Interessanti poi le possibili applicazioni relative alla visualizzazione volumetrica per i dati provenienti da indagini geofisiche, specialmente quelli forniti dal GPR (Ground Penetrating Radar).

Il Capitolo 8 (*Future developments*, pp. 125-132), che si chiude con un breve sommario dal carattere conclusivo, discute l'impatto che nuove tecniche e dispositivi stanno avendo sulla pratica archeologica, come le applicazioni del LIDAR o la possibilità di utilizzare tecniche di Machine Learning, e in particolare gli algoritmi di deep learning, per individuare e classificare caratteristiche archeologiche. Insomma, come osserva Gary Lock nella Prefazione, «In their final chapter the authors address future developments and include interesting areas such as the senses, movement and perception, aurality, and acoustics, a list that would move us even closer to modelling being human». Infine, un ricco apparato bibliografico chiude il volume, consentendo ai lettori di rendersi conto complessivamente delle reali dimensioni, della varietà e del livello tecnologico raggiunto in questo settore di studi.

In definitiva, l'opera di Dell'Unto e Landeschi offre al lettore un quadro completo dell'evoluzione metodologica e applicativa del GIS 3D in archeologia e lo fa nel modo più immediato ed efficace possibile, mostrando i risultati che derivano dalla sua applicazione. L'esperienza degli autori, spesso direttamente coinvolti nei progetti di ricerca da cui sono tratti i casi studio, risulta evidente ed accresce la concretezza con cui vengono descritte le problematiche scientifiche e le soluzioni tecniche adottate per farvi fronte. Al termine della lettura del volume non si può che confermare quanto emerge dalla premessa. La possibilità offerta dal GIS 3D di costruire un ponte tra diversi aspetti dell'archeologia digitale mediante l'integrazione di alcuni dei loro principali mezzi espressivi (il GIS e il modello 3D) si conferma come un affascinante stimolo di ricerca, che apre interessanti prospettive di indagini future.

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M. Figuera, *Past for the future: archeologia, conservazione e nuove tecnologie. Casi studio greci e italiani*, Antico, Edizioni Quasar, 2022.

Attraverso i risultati di progetti nazionali e internazionali, il volume propone una rassegna di applicazioni tecnologiche e approcci digitali per la comunicazione, la tutela e la fruizione del patrimonio archeologico. I casi studio esaminati sono relativi a siti di due macroaree affini: la Sicilia e Creta. L'ampio spettro delle azioni che il volume affronta, e che presentava il rischio di una miscellanea di difficile orchestrazione, trova un'efficace sintesi nel tema del digitale, che l'autrice ha affrontato con continuità negli ultimi anni, con un focus particolare sui dati (M. Figuera, *Un sistema per la gestione dell'affidabilità e dell'interpretazione dei dati archeologici. Percezione e potenzialità degli small finds: il caso studio di Festòs e Haghia Triada*, Praehistorica Mediterranea 8, Oxford, Archaeopress, 2020; M. Figuera, *A Fuzzy approach to evaluate the attributions reliability in the archaeological sources*, «International Journal on Digital Libraries», 22, 3, 2021, 289-296, https://doi.org/10.1007/s00799-020-00284-6).

La "polisemia" del dato digitale e il variegato potenziale informativo ne rendono oggettivamente difficile una rigida finalizzazione; da qui l'esplorazione dei diversi ambiti di utilizzo delle nuove tecnologie per il patrimonio archeologico, con un'apprezzabile dimensione storica introduttiva per ciascuna, che rende ragione dell'evoluzione di discipline e applicazioni. Altri temi sono trasversali all'intera trattazione e si intrecciano significativamente all'interno dei diversi capitoli. La sostenibilità del patrimonio archeologico, per esempio, in cui restauro, conservazione e tutela materiale si sovrappongono alla necessità di un turismo responsabile e di un più ampio coinvolgimento delle comunità per un più significativo impatto sociale.

Il Capitolo 1, dedicato a comunicazione e storytelling, affronta diversi di questi aspetti. Il potere dell'archeologo nella creazione di una narrazione del passato, potere che si fa politico ed economico, è oggi sostenuto da mezzi tecnologici di sicura presa sul grande pubblico, ma non è un fatto concettualmente nuovo. Il testo, infatti, rammenta giustamente il caso emblematico della Cnosso di Arthur Evans: «un'eterotopia, un modo di vedere cose non realmente viste, una forma al contempo istituzionalizzata e isolata di "banca dell'immaginazione" nella memoria collettiva cretese». Questione del ruolo dei social nella democratizzazione della fruizione o degli stakeholder nell'elaborazione di contenuti e proposte culturali sono alcuni dei passaggi più interessanti del capitolo, utili a riflettere su quanto Realtà Aumentata, visite immersive e copie digitali siano davvero strumenti neutri che, semplicemente, rendono più accessibile il patrimonio culturale. Certamente il loro contributo avvantaggia il racconto di siti archeologici particolarmente sfidanti come quelli affrontati nel volume: siti appartenenti al patrimonio diffuso o caratterizzati da strette integrazioni di senso tra paesaggio e insediamenti o siti multifase.

Queste esigenze aprono ad una dimensione ampiamente territoriale il patrimonio archeologico, come discusso nel Capitolo 2, dedicato a restauro, tutela e fruizione. Dopo un ampio *excursus* sulle strategie di conservazione, il discorso si focalizza, in particolare, sul tema delle coperture dei siti archeologici come strumento di "conservazione attiva". Alla fruizione quale ultimo passaggio della «filiera concettuale ricerca-tutela-valorizzazione» (D. Manacorda, *Archeologia tra ricerca, tutela e valorizzazione*, «Il Capitale Culturale», 1, 2010, 139) è, invece, riferito il cuore della trattazione sugli strumenti digitali applicati all'archeologia (realtà virtuali, ricostruzioni 3D, realtà aumentata, gamificazione), con una finalizzazione rispetto alle caratteristiche dei diversi scenari e passando da soluzioni indoor ad outdoor. In particolare, sono distinte tre grandi tipologie di strumenti per la fruizione: quelli per una fruizione dinamica e attiva (dimostrazioni di archeologia sperimentale, attività di reenactment); strumenti iconico-visivi (fotografie, disegni, pannelli informativi, modelli 3D, prodotti multimediali, segnaletica in generale); strumenti simbolici, in cui parole e dati numerici rivestono un ruolo preponderante (cartografia, guide cartacee e audioguide).

All'interno di tali categorie sono passate in rassegna alcune soluzioni tecnologiche più innovative e di impatto sui fruitori, come le "period room", allestite anche grazie alla Realtà Virtuale, o le "time machine", particolarmente indicate per la comunicazione dei siti multifase, accanto ad altri prodotti digitali oggi più largamente diffusi, come i modelli tridimensionali da laser scanner o fotogrammetria. Bubble viewer, emotional browsing, serious game, ArTGlass e altro ancora costituiscono ulteriori evoluzioni per l'utilizzo anche a carattere interattivo e/o immersivo di tali prodotti, in una dimensione sempre più fortemente sensorializzata della fruizione.

Il Capitolo 3 è dedicato alla descrizione dei casi studio, doverosamente introdotti da alcune considerazioni sulle affinità dei due macrocontesti di appartenenza, la Sicilia e Creta, nonché sulle caratteristiche cronologiche e tipologiche dei siti selezionati al loro interno (rispettivamente: Calaforno, Calicantone, Megara Hyblaea; Festòs, Haghia Triada). Alcune caratteristiche, in particolare, accomunano questi contesti: presenza di criticità ambientali, complessità dei siti (difficilmente accessibili o multifase), specifiche sfide di comunicazione, necessità di approcci digitali nell'acquisizione e trattamento dei dati. Per ciascun sito è proposta una breve storia degli studi, una descrizione, un'analisi delle criticità, un'esposizione degli strumenti di fruizione utilizzati.

Multidisciplinarità e tecnologia sono, all'interno del volume, gli strumenti chiave per affrontare la complessità in archeologia, con un approccio di carattere territoriale oggi imprescindibile. È merito del testo intrecciare continuamente all'esposizione di tecniche e strumenti l'idea che ciò non significhi semplicemente una particolare ampiezza in senso topografico del territorio analizzato, ma coinvolga la nozione di archeologia sociale del paesaggio e cioè di un'interazione uomo-ambiente che si snoda dall'antichità ai nostri giorni, in cui la presenza del patrimonio archeologico nelle comunità di appartenenza riveste un ruolo identitario fortissimo, sentito dal grande pubblico come confortante soluzione alla minaccia proveniente dalle politiche culturali sovranazionali e da una narrativa globalizzata. Perfino dal punto di vista del Diritto Internazionale, infatti, la nozione identitaria della cultura e la diversità culturale sono considerate ormai pietre miliari della dottrina, a partire dal General Comment n. 21 del 2009 sul diritto all'identità culturale messo a punto dal CESCR (Committee on Economic, Social and Cultural

Rights). In questa prospettiva, il volume fornisce un interessante contributo alla comprensione della complessa dimensione sociale dell'archeologia e delle sue implicazioni sia teoriche, sia materiali. Il patrimonio archeologico si configura infatti per una particolare suscettibilità alla costruzione di una funzione identitaria e pone la sfida alla costruzione di una comunicazione che sia allo stesso tempo oggettiva e inclusiva.

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D. Manacorda, M. Modolo (eds.), *Le immagini del patrimonio culturale, un'eredità condivisa?*, *Atti del Convegno promosso dalla fondazione Aglaia (Firenze 2022)*, Ospedaletto (Pisa), Pacini Editore, 2023.

Il volume pubblica gli atti del Convegno promosso a Firenze nel giugno 2022 dalla Fondazione Aglaia – Diritto al patrimonio culturale (https://www.fondazioneaglaia.it/), nata nel 2020 dalla trasformazione dell'Associazione culturale Past in Progress, che dal 2010 ha promosso la conoscenza del patrimonio culturale attraverso il coordinamento e la gestione di progetti di ricerca, didattica, divulgazione, educazione civica e valorizzazione dei beni storico-archeologici. Il volume, come il tema del Convegno, è incentrato sul dibattito riguardo il limite di utilizzo delle immagini del patrimonio culturale pubblico alla luce dello sviluppo e della diffusione capillare di mezzi tecnologici che ne accrescono le possibilità di diffusione.

Il libro, curato da Daniele Manacorda e Mirco Modolo, è articolato in tre sezioni: una prima ampia introduzione ai temi in oggetto e due parti che contengono gli interventi di rappresentanti di diverse discipline: nella prima parte compaiono giuristi, economisti, esponenti delle istituzioni (università, ministero, etc.) e rappresentanti delle associazioni, mentre nella seconda trovano posto le testimonianze di protagonisti dall'imprenditoria culturale e di istituti culturali pubblici e privati. A corredo degli interventi sono presenti illustrazioni in bianco e nero, spesso riproduzioni di inserti pubblicitari anche d'epoca, che descrivono efficacemente il cosiddetto "riuso" delle immagini di beni artistici e archeologici in ambiti essenzialmente commerciali, con l'intento di fornire un contrappunto ironico ai temi trattati.

Nella Premessa, a cura di Carolina Megale, rappresentante della Fondazione Aglaia, si descrivono efficacemente i tre tipi di approccio all'utilizzo iconografico del patrimonio culturale: il primo attribuisce ai beni culturali un valore fondamentalmente estetico, il secondo attiene alla concezione identitaria delle comunità che ospitano i beni e il terzo è relativo alle potenzialità di volano economico, non solo in relazione al cosiddetto mercato culturale, ma anche alle possibilità offerte dall'utilizzo di nuove tecnologie digitali.

Nella parte introduttiva, l'intervento di Daniele Manacorda (pp. 15-31) propone una sorta di decalogo per la piena liberalizzazione dell'uso delle immagini del patrimonio culturale, in particolare per scopi di studio e di ricerca. L'obiettivo auspicato coincide con il compito di educare le comunità a prendersi cura attivamente del proprio patrimonio culturale attraverso attività di conoscenza, tutela, valorizzazione, fruizione e comunicazione. Di particolare attualità il "decimo argomento" del decalogo che mette in luce le difficoltà ancora presenti, soprattutto nel nostro Paese, in relazione ad una fruizione aperta, ad una piena liberalizzazione delle immagini, anche in rapporto al recente Piano nazionale di digitalizzazione del patrimonio culturale (PND). Le considerazioni presentate da Manacorda sono attualizzate alla luce del decreto n. 161 dell'11 aprile 2023, con cui il Ministero dei Beni Culturali ha introdotto linee guida per la determinazione degli importi minimi per la riproduzione digitale dei beni culturali statali, compresi quelli in pubblico dominio. Il decreto ha suscitato accesi dibattiti e aspre critiche (cfr. da ultimo la delibera 20 ottobre 2023, n. 76/2023/G della Corte dei Conti), andando ad impattare negativamente sulla valorizzazione e diffusione del patrimonio culturale italiano nel mondo e sulla condivisione della conoscenza.

Mirco Modolo (pp. 33-69) compie invece un interessante *excursus* storico dal 1892 ai giorni nostri in cui si ripercorrono, anche attraverso documenti originali, i rapporti tra i produttori di materiale fotografico (tra gli esempi più noti quello dei Fratelli Alinari) e il governo, spesso noncurante del fatto che il materiale fotografico fosse il veicolo più rapido ed efficace di raccolta e catalogazione del patrimonio culturale: ciò porta a riflettere sul fatto che un problema sollevato più di un secolo fa sia in realtà ancora irrisolto. Oggigiorno, però, all'interno del dibattito si è inserito come prepotente protagonista il progresso tecnologico e le sue espressioni che hanno ripercussioni anche sul piano giuridico.

L'importanza delle fotografie per lo studio della storia dell'arte è chiaramente richiamata in una lettera che Vittorio Alinari scrisse al Ministro Pasquale Villari l'8 marzo 1892, in seguito alla presentazione alla Camera di un progetto di legge, di cui un articolo avrebbe riguardato l'imposta di una tassa sulla riproduzione fotografica dei monumenti esistenti in luoghi chiusi appartenenti allo Stato. Queste le parole del fotografo: «Quest'articolo, come mi viene comunicato, sembrami non solo ledere fortemente gl'interessi de' fotografi esercenti, che formano adesso, specialmente nella nostra città, un nucleo abbastanza rilevante, ma nuocerebbe altresì al progressivo sviluppo di quelle collezioni artistiche che sono di non dubbia utilità per gli studiosi, i quali si compiacciono ricorrere ad esse per quei raffronti necessari, in mancanza di documenti, a completare ed in certi casi rettificare la storia dell'arte».

Dopo questa parte introduttiva, nella "Parte prima: i punti di vista" si sussegue una serie di interventi che si soffermano su alcuni aspetti specifici, dando rilievo al punto di vista accademico (Giorgio Resta per gli aspetti giuridici, Grazia Semeraro per l'archeologia e i beni culturali, Massimo Fantini per gli aspetti economici), a quello dell'associazionismo (Andrea Brugnoli) e infine a quello del Ministero della Cultura, con particolare riferimento all'attività dell'Istituto centrale per la digitalizzazione del patrimonio culturale (Laura Moro). Tutti gli Autori sottolineano come nel campo dei beni culturali la possibilità di accesso e fruizione alla documentazione iconografica dovrebbe essere la regola, ovviamente con le limitate eccezioni decise dalle singole istituzioni.

D'altronde questa è la tendenza internazionale che si orientata verso l'apertura dei dati attraverso normative sempre più aderenti ai dettami della Convezione quadro del Consiglio d'Europa del 2005 sul valore del patrimonio culturale per la società (Convenzione di Faro), secondo cui la conoscenza e l'uso del patrimonio culturale rientrano a pieno titolo fra i diritti umani per cui è necessario creare nuove modalità di accesso e permettere forme innovative di fruizione. Sicuramente il Piano nazionale di digitalizzazione del patrimonio culturale (PND), approvato il 30 giugno 2022 e consultabile online (https://docs.italia.it/italia/icdp/) denuncia il grave ritardo italiano e offre indicazioni molto dettagliate sulle modalità tecniche della digitalizzazione, ma, nonostante l'apertura verso la politica dell'open access, continua ad avere problemi a perseguirla operativamente.

Nella seconda parte del volume sono presenti le testimonianze di esperti di varie discipline e di settori innovativi dell'editoria, della grafica e del design, che presentano le loro esperienze dirette e testimoniano quanto la cultura possa essere diffusa e comunque partecipata da soggetti anche non istituzionali. Si tratta di contributi che provengono da protagonisti che svolgono attività molto diverse tra loro e che illustrano un ampio panorama che va dal mondo della ricerca (Daniele Malfitana e Antonino Mazzaglia) alla gestione dei musei (Martina Bagnoli, Beppe Moiso e Tommaso Montonati) e degli archivi fotografici (Claudia Baroncini), e dal mondo dell'editoria e delle associazioni per la diffusione della conoscenza libera (Riccardo Falcinelli e Iolanda Pensa) all'industria culturale e a quella creativa rivolta all'intrattenimento elettronico (Stefano Monti e Fabio Viola).

In particolare, l'esperienza dei curatori museali e delle fondazioni trasmette ai lettori una conoscenza sulle modalità con cui i professionisti del patrimonio culturale, indicati con l'acronimo MAB – scelto dall'Associazione Italiana Biblioteche, dall'Associazione Nazionale Archivistica Italiana e dall'ICOM Italia per coordinarsi ed esplorare le prospettive di convergenza tra gli istituti in cui operano i professionisti degli archivi, delle biblioteche, dei musei – affrontino i temi delicati della valorizzazione e promozione delle proprie collezioni e di come si rapportino con il mondo degli studiosi. Come già emerso nelle pagine precedenti del volume, la classificazione e lo studio del materiale documentario visivo permettono di recuperare informazioni altrimenti impossibili da recepire e descrivere, specie trattando collezioni di grandi dimensioni. Da ciò deriva ancora una volta la necessità di semplificare l'accesso al patrimonio iconografico.

Nel panorama articolato che viene offerto dal volume sul tema del ruolo svolto dalle immagini per trasmettere e perpetuare l'eredità culturale del patrimonio, occorre sottolineare come da più di un intervento emerga che il concetto di "autorizzazione" è espressione della limitazione dell'interesse soggettivo nei confronti di un interesse collettivo. Un esempio spesso citato come possibile risposta alle questioni sollevate è l'infrastruttura Europeana, un'unica piattaforma che ospita le collezioni digitali di tutti gli stati membri e che costituisce al contempo un modello di approccio collaborativo e, operativamente, un laboratorio per sperimentare le possibilità offerte dal digitale.

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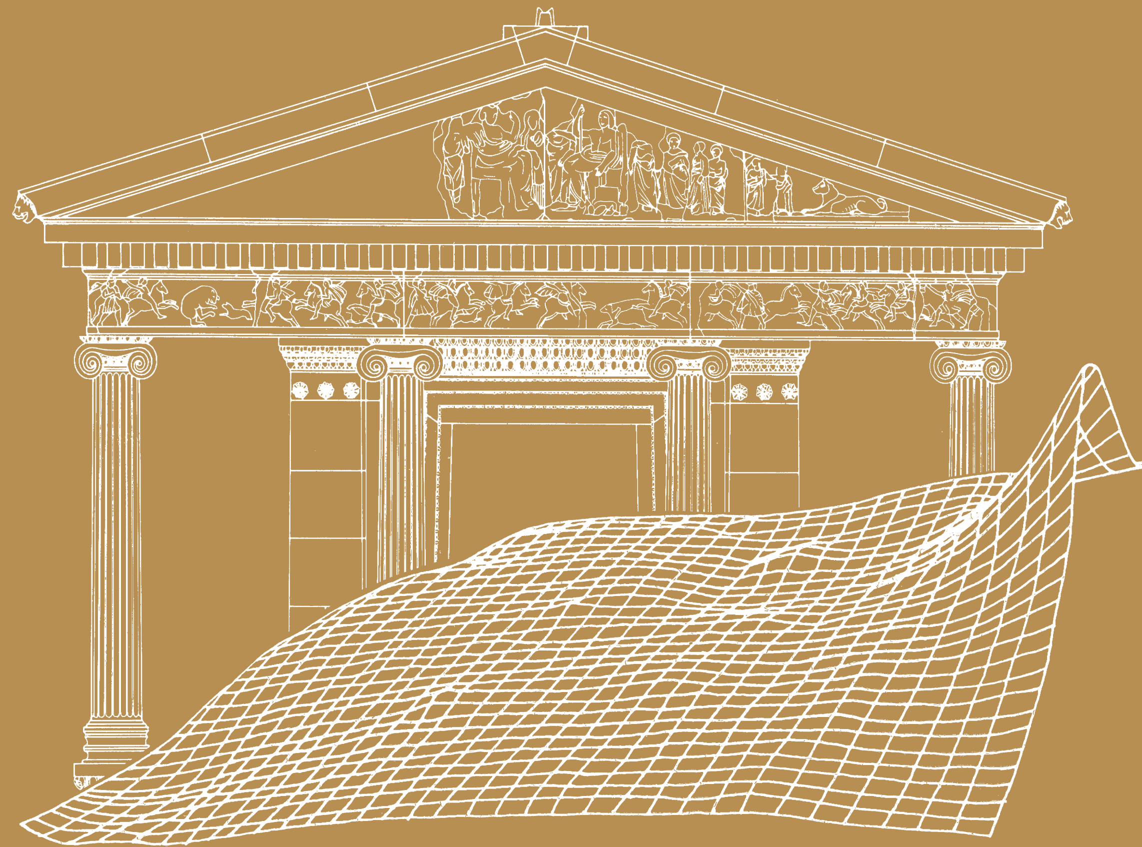

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