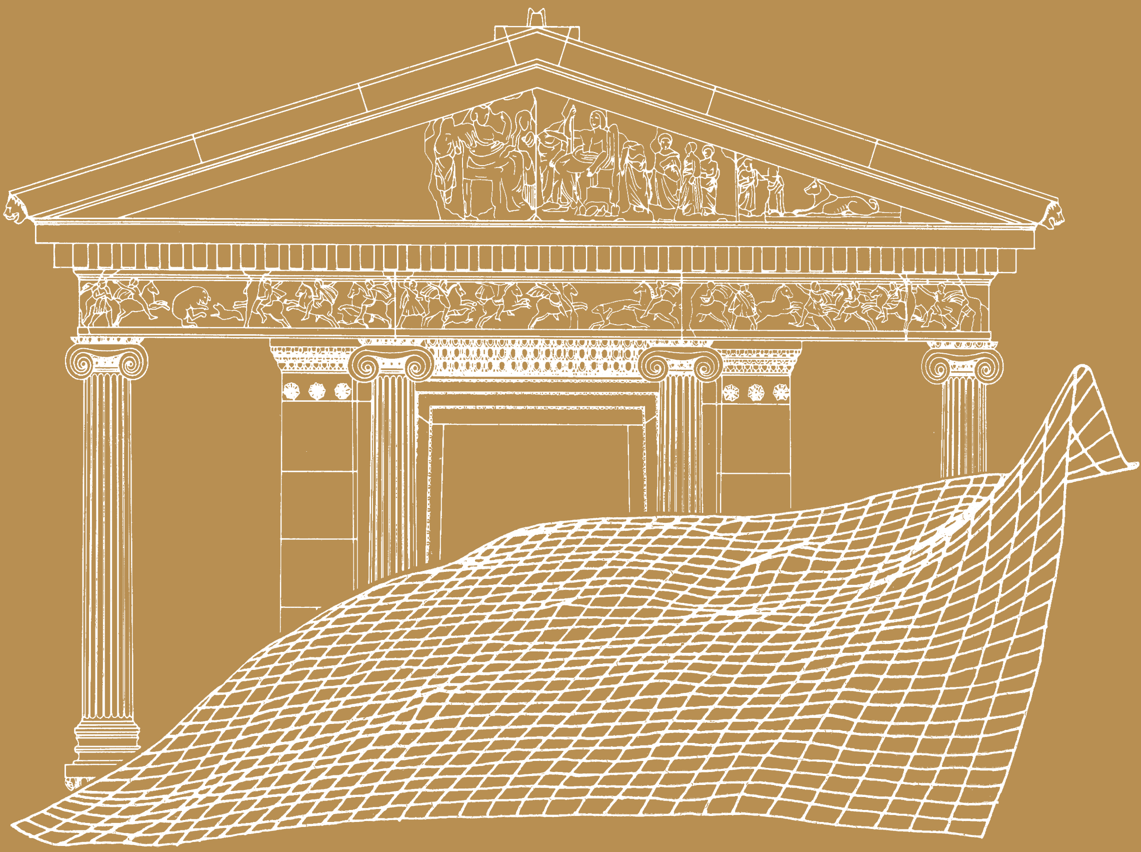

# ARCHEOLOGIA E CALCOLATORI

# 34.1

2023

*All'Insegna del Giglio*

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# INDICE

# ARCHEOFOSS 2022
# PROCEEDINGS OF THE 16[TH] INTERNATIONAL CONFERENCE ON OPEN SOFTWARE, HARDWARE, PROCESSES, DATA AND FORMATS IN ARCHAEOLOGICAL RESEARCH
# (ROME, 22-23 SEPTEMBER 2022)

edited by

Julian Bogdani, Stefano Costa

**Archeologia e Calcolatori**
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# INTRODUCTION

The 2022 edition of ArcheoFOSS was hosted at Sapienza University of Rome on 22-23 September, in collaboration with the LAD (Laboratory for Digital Archaeology at Sapienza) and the DigiLab (Interdepartmental Research Centre of Sapienza University of Rome), as a hybrid event, both online and in presence. The funding and sponsorship from the Direzione Generale Educazione Ricerca e Istituti Culturali of the Ministry of Culture has been equally important, both at the financial and institutional level, supporting the ArcheoFOSS association to organise previous meetings and to publish their proceedings in a timely manner. As is made clear by looking at the venues of the past 16 years, ArcheoFOSS does not belong to a single research institution, as the yearly "migration" from one city to the next goes on, for now in Italy but hopefully, in the future, also abroad.

The conference programme spans a wide range of topics, organised in thematic panels. Ranging from archaeological fieldwork to theoretical approaches, the two days of the conference have seen researchers from different countries share their work and perspectives about research processes and projects following the Open Science paradigm: open source software tools, open formats and open methodology both for investigation and dissemination. This includes issues like interoperability, data and knowledge sharing, for which open source software has been at the forefront for several years now, both in the specific field of archaeology and the wider scholarly world.

The 2022 edition was based for the first time on panel sessions that provided an opportunity for expert members to present their views and share their experience on a specific topic and then engage in a discussion with the audience. Panel proposals were solicited from community members, scholars and professionals willing to discuss research questions and experience and stimulate further discussion of specific topics. The call for panels went through a public discussion in the GitHub repository of the conference, allowing community members to provide early feedback on the very structure of the conference through an open, not anonymous, peer-review process. The same approach was followed with the call for papers: each proposal was submitted directly through the "pull request" functionality of the repository or uploaded by the organisers. An open peer-review allowed the authors to address questions and to see in advance the other papers in the same panel. The eight panels were (in order of appearance in the conference programme):

1. Archaeological stratigraphy data (panelists: Stefano Costa and Emanuel Demetrescu).

2. GIS open source solution for archaeological context in between Universities, Public Administration, societies, research center: the pyArchInit case (panelists: Enzo Cocca and Gianluca Martinez).
3. Practice and paradigms of open source technologies for archaeological field data (panelists: Fabian Riebschläger and Thomas Kleinke).
4. I/O: ethics, policies and technologies for programmatic and open access to archaeological online data sets (panelists: Julian Bogdani and Riccardo Montalbano).
5. Electronic publishing and Open Science in Archaeology (panelists: Alessandra Caravale and Alessandra Piergrossi).
6. From wiki projects to OpenStreetMap, collaborative approaches to open data creation: problems, case studies, territorial and cultural impact (panelists: Saverio Giulio Malatesta and Paolo Rosati).
7. Moving in the past: open solutions for data set design, spatial analysis and spatial statistical methods to investigate movement in Antiquity (panelists: Domizia D'Erasmo and Noemi Giovino).
8. Maps to the past. Open digital approaches to the investigation of historical maps (panelists: Julian Bogdani and Valeria Vitale).

During the conference, some panels had an introduction or a discussion by well known researchers who were specifically invited, such as Paola Moscati, Anita Graser, Drake Zabriskie and David Rumsey. After the presentations, panels were followed by a lively and focused discussion: the chance to have something better than the traditional Q&A was well received by the participants and in our opinion is a strong indication for future ArcheoFOSS conferences. All presentations were in English, apart from those in the pyArchInit session, all with a strong focus on Italy. The most crowded panel was "Electronic publishing and Open Science in Archaeology" with eight papers presented.

We are proud to realise that the basic idea behind the ArcheoFOSS conferences is no longer a niche topic within the archaeological discipline. The Open Science paradigm has experienced a very rapid diffusion in many contexts and regulations of financing programmes, both national or international, are more and more focused not only on the open access of the research results, but also on a deeper awareness on availability of the data. The generalised application of the FAIR principles is determining a gradual change in the way the archaeological data are being collected, studied, and communicated. The change of policy in favour of Open Science in the archaeological discipline is determined and sustained by a general trend in European institutions and we are glad to observe how the ArcheoFOSS annual conferences are progressively evolving from the meetings of a limited number of enthusiast pioneers towards an internationally participated community of researchers, perfectly convinced on the importance of wide, virtually global, and multi-levelled collaboration of different actors in our field of research.

While the drafting of these conference proceedings was being concluded, in Italy the Ministry of Culture has introduced the guidelines for the determination of minimum amounts of fees for the reproduction of cultural heritage with the decree number 161 of 11 April 2023, rejecting much of the work carried out by the digital library general directorate of the same ministry just last year with the ICDP - National plan for the digitization of cultural heritage (https://www.cun.it/uploads/7711/Raccomandazione_18_05_23.pdf).

The ArcheoFOSS community has always promoted the freedom of access and use of images of cultural heritage, therefore we follow with concern the ongoing developments, working with other organizations for a modification of the guidelines that respect the public service mission inherent in the role of the Ministry of Culture.

*Acknowledgments*

The conference would not have been possible without the tireless work of many students and colleagues. Special thanks go to Domizia D'Erasmo for her tireless contribution and support.

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# THE HARRIS MATRIX DATA PACKAGE SPECIFICATION AND THE NEW INIT COMMAND OF THE PYTHON HMDP TOOL

## 1. Harris Matrix Data Package

Harris Matrix Data Package is a lightweight and user-oriented format for publishing and consuming archaeological stratigraphy data. Harris Matrix data packages are made of simple and universal components, they can be produced from ordinary spreadsheet or database software and used in any environment. Harris Matrix Data Package is entirely based on the data tables proposed for the "hm" Lisp package (Dye, Buck 2015), with the important addition of metadata from the Frictionless Standards specifications. As the "hm" documentation states «There are seven data tables potentially used as input to hm. A project requires a table for units of stratification and for observed stratigraphic relations, but the other five tables are optional». Data tables are CSV files and the metadata descriptor is a JSON file.

Harris Matrix Data Package was first presented at ArcheoFOSS 2019 (Costa 2019), but it has not seen any significant adoption, despite important work in the area of long term and sustainable archiving of stratigraphy data (Moody *et al.* 2021). When looking at the limitations of the initial proposal for the data format, the lack of a clearly documented specification, that must be kept separate from the software tool, was identified as the main issue. The data format specification is now presented as an RFC-style document at the stable URL https://www.iosa.it/specs/harris-matrix-data-package/.

From the point of view of Frictionless Standards, Harris Matrix Data Package is a Data Package "profile" similar to the Fiscal Data Package (Walsh *et al.* 2018) or the Camera Trap Data Package (Camtrap DP Development Team 2022). The following definitions apply in the context of the Harris Matrix Data Package specification:

– "data descriptor" is a JSON file, named "datapackage.json", that is found in the top-level directory of a data package, and contains metadata about the entire data package (name, description, creation date, author names, references) together with the data package schema;
– each "resource" is a CSV table;
– "contexts" refer to archaeological stratigraphy units as produced by the single context recording method; contexts can be both positive and negative and are described in terms of unit-type and position;
– "observations" refer to the stratigraphic relationship between pairs of contexts, and can only record relative chronology of earlier-later relationships

– sameness and contemporaneity of contexts are treated separately in the "inferences" table;
– "inferences" refer to once-equal contexts that were recorded separately, but get treated as a whole for the purpose of stratigraphy, as is the case of a floor level that was divided in two separate units by a later trench;
– "phases" and "periods" are groupings of contexts that are based on chronological affinity;
– "events" are associations between absolute chronology events and contexts, and the resource specifies the nature of the association (Dean 1978);
– "event-order" is an indication of the order of absolute chronology events related to the same context.

The simplest Harris Matrix Data Package will contain three files in one directory: datapackage.json, contexts.csv and observations.csv. This basic layout is capable of recording all directly observed stratigraphic relationships, that can be processed into a directed acyclic graph (DAG) and visualized as a Harris Matrix. The five optional tables alter the graph, by providing instructions for merging one or more stratigraphic units in a single graph node, for grouping nodes with visual indication of their phase or period, for adding nodes to the graph from absolute chronology events, in a specific order. At present, the format can be read using the "hm" Lisp software, the "hmdp" Python software described below and the R "stratigraphr" library (with a few intermediate steps through the "frictionless" library). The only known implementation of a writer is the "hmdp init" command.

The Harris Matrix Data Package is not necessarily the best native format for an archaeological information system, because they are typically modeled as relational databases with a much wider scope. However, the combination of simplicity in the choice of file formats with detailed machine-readable metadata is a good tradeoff that should make it a good, if not optimal, exchange and archival format.

## 2. The hmdp tool

The hmdp tool (always spelled in lower case) is a command line program with three separate subcommands: init, check and matrix. This tool is developed as a minimalist and versatile proof of concept for a more complete stratigraphy software package, but it could also be reused as part of other existing applications, like pyArchInit (Mandolesi, Cocca 2013). The version that is referred to in this paper is hmdp 2022.10.16, released under the GNU GPLv3 license (Costa 2022). hmdp is written in the Python programming language and depends on foundational open source libraries such as NetworkX, pygraphviz and Graphviz (Gansner, North 2000; Hagberg, Schult, Swart 2008) for processing of stratigraphy data into a directed acyclic graph. The data package is read into the program with the functions provided by the "datapackage" and "goodtables" Python libraries (now superseded by the "frictionless" library).

### 2.1 *The new init command*

The init command can create a new, empty data package from scratch, consisting of the metadata descriptor and empty data files, easing the creation of data packages that otherwise would require several manual steps and editing of text files. The naming and functionality are inspired by the well-known "git init" command, although in this case "hmdp init" will accept command line arguments for the data package name, author, and resource presets (described below in further detail). If no argument is provided, an interactive prompt in the terminal asks the user to provide the same data and populates the datapackage.json file.

Based on the amount of information available, "hmdp init" provides four presets with an increasing level of detail (the numbering in the list correspond to the numbers associated with each preset in the command line interface):

1. contexts and observations (basic data model);
2. contexts, observations and inferences, to add data about sameness or contemporaneity of stratigraphic contexts, which is necessary to reconcile the difference between the traditional Harris Matrix that allows to define two contexts as equal but still separate, and the need to merge such units in the DAG model;
3. contexts, observations, inferences, periods and phases, a second step towards complexity, with the periods and phases as loosely defined as possible in order to allow multiple levels of chronological periodisation;
4. contexts, observations, inferences, periods, phases, events and event order, the entire set of resources that is only supported by "hm" for analysis but can still be added and managed.

The presets listed above were chosen to simplify the creation of data packages, without forcing users to make all-or-nothing choices. In particular presets 2 and 3 allow to create data packages of intermediate complexity. It is always possible to edit the data package at a later stage, add or remove resources, but this requires small changes to the schema of foreign keys that is not supported by the version of the program described here: for example, if the data package is created with preset 3, then the "contexts" resource schema will contain a "foreignKey" referring the "periods" and "phases" resources, and removing those resources without removing the corresponding "foreignKey" returns a broken data package. A simplistic workaround to all these small limitations would be to always create a complete data package, with example data in all resources including those that are not actually used, but this was not deemed correct. In general, the hmdp init command is agnostic to the subsequent steps taken either with other software or with hmdp itself. The stated aim is, again, to enable different tools to interoperate with the same data format.

### 2.2 *The check command*

The check command is a useful shortcut to run all available validation tasks on the data package. The command must be given only one argument, the datapackage.json, and will perform three checks on the dataset:

– validate the metadata descriptor without looking at the data (e.g. resources can be missing or broken but the JSON file is well formatted);
– validate every resource for internal consistency (e.g. there are column headers, each row has the right number of columns, constraints like integer values, enums, etc. are respected);
– check the consistency of foreign keys based on the data descriptor.

Ideally, this command would be run after each modification to the resource files and to the metadata descriptor.

### 2.3 *The matrix command*

The core functionality of hmdp is in the matrix command. The matrix command takes two arguments, the input data package and the output Graphviz DOT file, in the same vein as "hm", even though hmdp is quite limited if compared to its Lisp predecessor. All contexts are read from the "contexts" resource, optionally assigning an attribute for a different graphical shape corresponding to the unit type (the "hm" documentation mentions three possible values: deposit, interface, other). Each context is added to the graph as a node. Observations of all stratigraphic relationships are added to the graph as "directed edges" from the younger node to the older node: this direction of the stratigraphic relationship is consistent with the single context recording methodology. If there are no cycles in the graph and a formally correct DAG can be created, the last processing step is the removal of redundant relationships with the "transitive reduction" function of NetworkX. Transitive reduction is also available as a Graphviz command "tred", but using NetworkX within the same Python program has the advantage of returning a DOT file that does not need further data processing, making the procedure more reproducible and in line with Open Science good practice (Marwick 2017). The graph is exported to the output Graphviz DOT file with the "ortho" layout attribute, so that edges will be drawn as orthogonal polylines.

The resulting DOT file is a digital representation of the Harris matrix that can be visualized in graphical form, with stratigraphic units represented as "nodes", possibly of different colors and shapes. The most effective way to obtain a static image is to run the Graphviz "dot" command, that will output a PNG or SVG file.

A crucial assumption of this two-step processing (from data to Graphviz, from Graphviz to image) is that multiple visualization outputs are possible from the same initial data. We are moving beyond the idea that the Harris Matrix is an output that is created (either manually or digitally) and then literally looked at in order to obtain information and seek answers, towards a research process where stratigraphy data is transformed and manipulated in a transparent way to obtain different chronological models that help with specific research questions.

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ABSTRACT

This paper presents an update to an earlier proposal for a standardized open format for archaeological stratigraphy data, the Harris Matrix Data Package, and the accompanying software tool implementation. The update is two-fold: firstly, it aims at a clear separation between data format and the software tool, particularly by defining the data format in more detail and independently from the software used to create or analyze it; secondly, it introduces a new software feature that allows the creation of a new 'data package' from scratch. A third issue that was identified is the lack of tools for converting existing data to and from the Harris Matrix Data Package, but this issue is not dealt with in this paper.

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# EMDB: YET ANOTHER DB FOR THE STRATIGRAPHIC RECORD

## 1. Why another database for the stratigraphic record?

Formalised stratigraphic documentation through the use of context sheets is considered an indispensable tool of a modern archaeological excavation alongside textual, photographic and graphic documentation. Despite recent evolutions in the field of indirect survey, especially with the introduction of photogrammetry and the return of colour in the archaeological graphical documentation as a tool to record stratigraphy (Drap *et al.* 2017), the formal description of context (stratigraphic) units still remains the starting point of any scientific investigation. It is the ability to access this information through accurate representations of archaeological excavations that have seen a steady and consistent evolution from 2D GIS to examples of interactive virtual reality (Opitz, Johnson 2016). Despite the relative simplicity of the context sheets apparatus, this requires special attention to its formal correctness and database architecture so that it remains compatible with other excavations and is re-deployable in different archaeological record management platforms.

On the other hand, the computer training that is provided within university training tracks is often not sufficient to make the archaeologist autonomous in creating his or her own working database. In addition to the dilemma as to whether a humanist actually needs to have detailed expertise on data architecture in order to do his or her job, this places a heavy burden on this professional figure. Although there are many solutions for digitally recording stratigraphic data, it should be noted that the most reliable tools are mainly based on online infrastructures and/or require specific GIS skills. Some of the current projects pushing this integration and promotion of digital technologies into the archaeological workflow and display of results include pyArchInit (Mandolesi, Cocca 2013), iDAI field 2 (Cuy *et al.* 2017), and BraDypUS (Bogdani 2022).

Following this line of projects, the ambition of this article is to open a discussion on the opportunity to have "facilitated access" to a database in order to record some vital actions that the archaeologist has to perform in the excavation. Hence the idea of sharing with the scientific community a pre-set database to create stratigraphic documentation in an autonomous way to obtain a digital output that can be shared, published, maintained for the long term, reused in other projects or imported within more evolved and performing platforms to be indexed and made searchable by the scientific community.

In this regard, the present research has extended the functionality of existing software, EMtools add-on for Blender (Demetrescu, Sala 2022), so that information can be included and visualised within the 3D space according to the well-known 3D GIS metaphor in which semantic objects (proxies) are linked to individual records in the database and integrated with the Extended Matrix (EM) Open-Science project. In the next sections, the Extended Matrix database (EMdb) will be described from a technical point of view focusing on the USM (Masonry Stratigraphic Unit) sheet (§ 2) and on the USV (Virtual Stratigraphic Unit) sheet (§ 3), using SQLite format, and examples of 3D visualisations of the record within Blender-3D (§ 4). An analysis of the current limitations and future work will be provided (§ 5). The general conclusions of the research will close the contribution (§ 6).

## 2. The EMdb hypothesis: the creation of the SQLite database

The starting point for the creation of the first part of the project was the retrieval of the USM sheets from the institutional website of the Istituto Centrale per il Catalogo e la Documentazione (ICCD)[1] in PDF format. The decision to use this scheme was based on the fact that it constitutes a standard adopted by the majority of the Italian archaeological community in excavation work. From this documentation, it was decided to use, for now, only the items on the first page of the document in order to create a simplified example. The items used are indicated in Tab. 1 below.:

The decision to use SQLite[2] as the application for creating the database came about because we identified the possibility of using a Python connector to link this file format with Blender. It also allows for connecting with the open source software LibreOffice Base[3]. The SQLite database was created using the open source software SQLiteStudio[4]. Thanks to this software, it is possible to design a database without having to write command line strings. In fact, the data structure is modelled via a simple graphic interface. For each item indicated above, a column has been built, for which the properties of the data within it have been specified. All information contained must be in TEXT format, i.e. with the possibility of containing both letters and numbers. The only special feature concerns the first USM column, which may never be empty (if it is empty, the software automatically highlights its non-presence as an error) (Fig. 1).

After the construction of this database, it was decided to connect it with the open source software LibreOffice Base. This decision was due to the fact that it is easier to use and has a better graphical user interface than SQLite. Unfortunately, to enable the SQLite capabilities in LibreOffice, it is mandatory to download an external ODBC (Open DataBase Connectivity) driver: the

[1] http://www.iccd.beniculturali.it/it/ricercanormative/170/us-usm-schede-%20per-il-rilevamento-sul-campo-delle-unit-stratigrafiche (accessed 01/09/2022).

[2] https://www.sqlite.org/index.html (accessed 14/01/2023).

[3] https://it.libreoffice.org/ (accessed 14/01/2023).

[4] https://sqlitestudio.pl/ (accessed 14/01/2023).

| SQLite field names - (table: "USM_sheet") | |
|---|---|
| Italian | English |
| USM | MSU |
| Ente responsabile | In charge institution |
| Anno | Year |
| Ufficio MIC competente per tutela | In charge MIC office for protection |
| Identificativo del saggio stratigrafico/dell'edificio/della struttura/della deposizione | ID of stratigraphic test pit/building/structure/burial |
| Località | Location |
| Area/edificio/struttura | Area/building/structure |
| Saggio | Test pit |
| Ambiente/unità funzionale | Room/functional unity |
| Posizione | Position |
| Settore/i | Sector |
| Quadrato/i | Square |
| Quote | Altitude |
| Piante | Map |
| Prospetti | Prospects |
| Sezioni | Sections |
| Fotografie | Photos |
| Misure | Measurement |
| Superficie analizzata | Analysed surface |
| Definizione | Definition |
| Tecnica costruttiva | Building technique |
| Funzione statica | Static function |
| Modulo | Module |
| Criteri di distinzione | Distinction criteria |

Tab. 1 – Items inserted in the SQLite database.

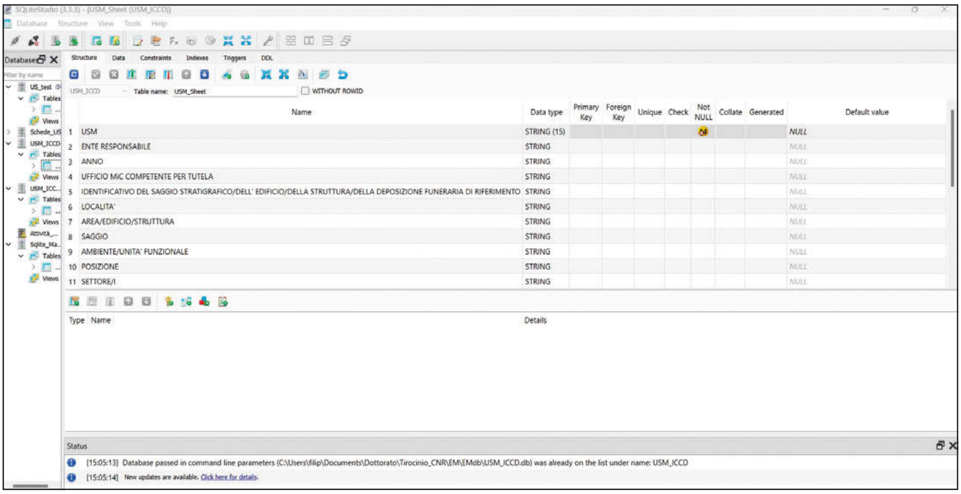


Fig. 1 – The SQLite database of the USM sheets.

connector setup C:\Programmes\LibreOffice\program\odbcconfig.exe (tested only on Windows, but a version of the driver exists for MacOS) allows LibreOffice Base to be configured with SQLite. Once this step has been taken, it is possible to open the previously created database directly with this software by changing its display through the creation of a mask. We decided to create a block mask imitating the USM tab of the initial ICCD in such a way as to make it as user-friendly as possible and already prepared as a print layout.

### 3. EMdb template for virtual reconstruction

Another strong aim of this article is to make a working prototype database that is versatile and inclusive to the incoming information of an archaeological/heritage project, rather than making the projects have to adapt to a system. The study of the historic and archaeological record is made of different disciplines that require recording diverse details and perspectives: archaeological fieldwork, as explored above in this paper, field survey, conservation and preservation, geographical studies, restoration, public engagement, and virtual reconstructions, to mention a wide range. Therefore, the next step was to build a workflow that permitted different subject areas to cooperate and integrate data into a centralised system.

The EM methodology offers the possibility to integrate many involved experts through the usage of the EMdb acting as a pivotal tool able to ingest different dataset within the Blender 3D visualisation experience. Any interested research group will be able to create a customised EMdb "adaptor" for their own database of records and make them readable in Blender. Nevertheless, certain ongoing projects are also creating EM compatible templates of context sheets shaped for different subjects that will ease this procedure. An example of the latter will be explained below. Thus, the aim of expanding and popularising the usability of the EMdb is to improve the standardised recording of information, but also to allow the scientific community to keep building future research on top of it.

The first database that has been included within the EMdb is one related to the documentation of virtual reconstructions. The recording of these models through the use of USV is quite novel and still in development through the Extended Matrix project. With the EMdb proposal, we have tried to gather the most important information of these units into a single table. The suggested database will help to document virtual reconstruction models using the accessible and FLOS (Free Libre Open Source) software LibreOffice and following a similar structure to the archaeological Stratigraphic Units (US) extensively to ease their understanding and usage. Nevertheless, the information is adapted to the new requirements of virtual elements and combines previous methods of recording USV such as the forms presented by the University of

| USV.v0 database elements | | |
|---|---|---|
| General information | Virtual Stratigraphic Unit | Metadata and Paradata |
| Number of USV | Type of unit | Documentation |
| Type of nodes | Subtype | Related EM nodes |
| Site name | Chronology (in years) | Level of knowledge |
| Site area | Period | Primary hypothesis |
| Recorded by | Phase | Alternative hypothesis |
| Date recorded | Description | Image |
| | Virtual Activity | |

Tab. 2 – Information requested in Version 0 of the USV database.

| | Name | Node | Chronology Start | Chronology End | Period Start | Period End | Description | Level of Knowledge |
|---|---|---|---|---|---|---|---|---|
| 1 | 6312# | USV | 98 AD | 300 AD | Roman | Roman | Mirrored Reconstruction of the Amb.14, underlayer of the pavement | 7. Basic Archaeological Info / Simple planimetry |
| 2 | 6317# | USV | 98 AD | 300 AD | Roman | Roman | Mirrored Reconstruction of the Amb.14, north-south orientated wall on the western side of the room, separating Amb.15-Amb.16. | 7. Basic Archaeological Info / Simple planimetry |
| 3 | 6318# | USV | 117 AD | 300 AD | Roman | Roman | Mirrored Reconstruction of the Amb.14, north-south orientated wall on the western side of the room | 7. Basic Archaeological Info / Simple planimetry |
| 4 | 6319# | USV | 98 AD | 300 AD | Roman | Roman | Ricostruzione speculare de la struttura muraria in opera listata, con orientamento est-ovest, costituisce il limite sudest dell'ambiente 14 | 7. Basic Archaeological Info / Simple planimetry |
| 5 | 6320# | USV | 117 AD | 300 AD | Roman | Roman | Reconstruction of the eastern marbol stairs | 6. Detailed Graphic Reference |
| 6 | 6321# | USV | 117 AD | 300 AD | Roman | Roman | Reconstruction of the eastern wooden stairs | 3. Simple Textual Reference |
| 7 | 6322# | USV | 117 AD | 300 AD | Roman | Roman | Reconstruction of the eastern wooden stair handrail | 2. Simple Parallel Hypothesis |
| 8 | 6323# | USV | 98 AD | 300 AD | Roman | Roman | Mirrored Reconstruction of the Amb.14, east-west orientated wall on the southern side of the room | 7. Basic Archaeological Info / Simple planimetry |
| 9 | 6324# | USV | 117 AD | 300 AD | Roman | Roman | Reconstruction of the eastern wooden stair handrail | 2. Simple Parallel Hypothesis |
| 10 | 6325# | USV | 117 AD | 300 AD | Roman | Roman | Mirrored Reconstruction of the western wooden stairs | 3. Simple Textual Reference |
| 11 | 6326# | USV | 117 AD | 300 AD | Roman | Roman | Mirrored Reconstruction of the western wooden stair handrail | 2. Simple Parallel Hypothesis |

Fig. 2 – Version 0 of the USV template.

Alicante in 2015 (Molina-Vidal, Muñoz-Ojeda 2015), the Graphic Scale of Historic-Archaeological Evidence (Aparicio-Resco, Figueiredo 2016) and the information of the graphML[5] from the Extended Matrix (Demetrescu 2015; Demetrescu, Ferdani 2021).

In this version 0 of the USV context sheets, the fields that have been suggested are divided into sections or areas. Some fields will have a vocabulary that will ease the usage and standardisation of the files, while other fields will allow free input of information. The basic structure of the record is shown in Tab. 2.

The information recorded through this table (Fig. 2) has provided positive results for the recording of reconstructive models. This template aims to simplify both the creation of the reconstruction through the organisation of ideas and the recording of the USVs. Furthermore, this information will be directly visualised over the 3D representation thanks to its link through the EMtools, as will be explained in the next section of this article.

## 4. 3D representation of stratigraphy

The focal point of the project is the use of this new feature of the Extended Matrix add-on (EMtools version 1.3.1) within the open source software Blender. The use of this new feature will make it possible to link all data contained in databases (Fig. 3) with individual 3D objects represented by the EMgraphdb

[5] http://graphml.graphdrawing.org/ (accessed 14/01/2023).


Fig. 3 – Example of a USV database in tabular format using SQLiteStudio.

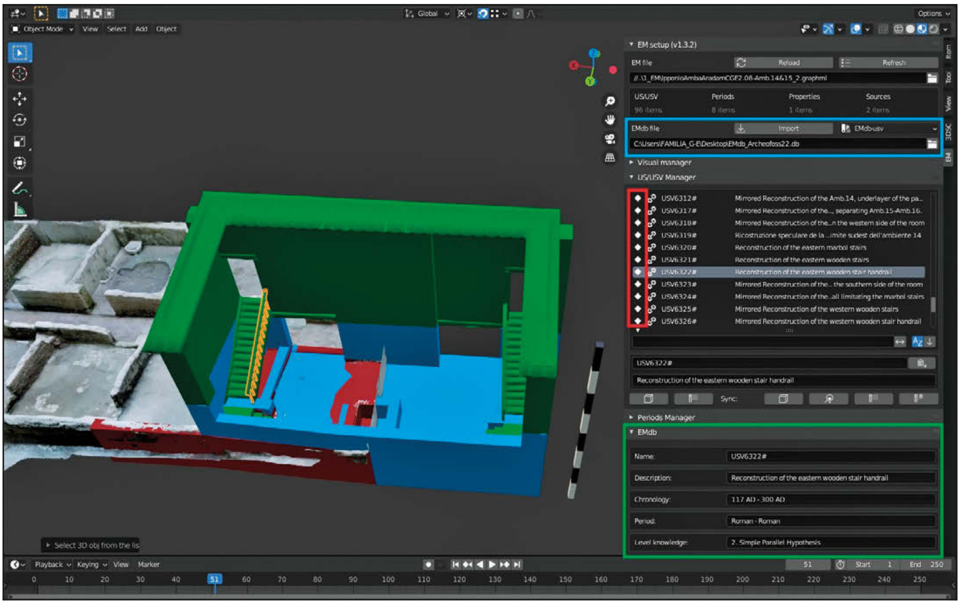


Fig. 4 – Screenshot of the Blender EMtools displaying a linked USV database through the EMdb feature.

(graphML file) and to visualise them in Blender. The following is a step-by-step description of the procedure and the resulting graphical representation.

The first step is to import the SQLite file (in our case saved with a *.db extension) into the software environment. To do this, it is necessary to select the file via the feature (called EMdb file) immediately below the field relating to the *.graphML file (squared in blue in Fig. 4) and then click on import. Once this operation has been carried out, if there is a match between the database and the data contained within the graphML file, a white diamond-shaped icon will be displayed in the panel called US/USV Manager (squared in red in Fig. 4). If there is no such correspondence, the icon will remain empty. By clicking on each entry of the US/USV Manager panel, the related information will be displayed in the form of a table shown below called EMdb (squared in green in Fig. 4).

The data displayed will vary depending on the database type (USM, USV, etc). In the case of USMs, the main information will be the name of the USM, its summary definition, its chronology/period and the construction technique. However, in the case of USVs, other data relating to its level of knowledge or documentation will also be displayed since they are part of the data recorded in the above-shown USV.v0 template.

## 5. Limitations and future work

During the development of this project, the authors encountered a series of limitations that should be highlighted for future works. At present, it is possible to connect only one external database into Blender (through EM-tools); hence, currently, it is not possible to connect both information coming from USM data sheets and from USV data sheets. Furthermore, data from related tables (lists of stratigraphic relations for each US, lists of photos or other sub-elements) are not yet considered. Another limitation is the poor flexibility of the user interface that exposes the content of the fields of the database due to the fact that it is currently hard-coded in Python and it is not customizable (i.e. through a configuration file).

Therefore, the natural next step for this project will be to develop a robust "EMdb importer" with the following features: multiple db import and manage, the possibility to work directly with SQLite files and 3D models (even without an EMgraphdb file) for quick visualisation and inspection of datasets, support for JSON based configuration files to make compatible different databases as well as to customise the UI to show information more smoothly. Furthermore, the ideas started during this project will be continued by the PhD studies of two of the authors of this article.

Promoting the use of the EMdb could open up new developments in the use of this plugin. An example of this can be seen in the work-in-progress PhD project of one of the authors of this contribution (Sala 2020-2023).

The potential of being able to link external databases developed using SQLite would allow additional information to be connected to the proxies in the Blender environment that would better describe the archaeological architectural characteristics of the elements represented, thus starting the fusion of the EM methodology with Building Information Modelling (BIM).

In addition, the integration and complementarity of different disciplines and studies within the EM methodology are one of the main topics of the PhD from Cristina Gonzalez-Esteban. She will promote and test the possibility of adding different databases linked through 3D visualisations. Her study area focuses on the historic landscape around Lake Yaxha (Guatemala), aiming to increase large-scope studies of the settlement patterns of the Maya Archaeological Sites of the area.

## 6. Conclusions

This contribution highlighted some limitations that are still present within the Digital Archaeology domain, namely the accessibility of open source, ready-to-use and standardised desktop-based database tools for data ingestion, management and sharing related to archaeological stratigraphy sheets. The idea is to provide the community with an interoperable and customizable series of "Plug & Play" templates within the main Extended Matrix repository (Demetrescu 2022) in order to operate in different scenarios, some of which are presented in this paper, namely the USM sheet (Italian Masonry Stratigraphic Unit Sheet) and the USV (international Virtual Stratigraphic Unit at its tentative version 0). We encourage the community to start from the templates and modify them to provide back new templates customised for other different scenarios (e.g. the creation of new context sheets for the analysis of the degradation of the surfaces within the restoration domain). Thus, with this contribution, a full set of instructions to create from scratch a compliant database that can be imported in Blender 3D (via the EMtools add-on) is provided. This project, still in its initial phases, aims to continue developing more customizable options to make the reuse of the described approach easier.

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## ABSTRACT


The collection of stratigraphic data has been done for years with offline tools like the Microsoft Access software, which was considered a user-friendly tool with the ability to print standardised context sheets (like the Italian ministerial US sheets) directly and 'without' the need for technical expertise. It is well known to the scientific community the limitation inherent in this type of approach: the data is not shared online and is not easy to be collaboratively edited; the data is locked within a proprietary format with repercussions on medium- to long-term preservation; and it is not immediately possible to integrate the data with other projects due to a lack of precise reference standard. Despite these issues, the offline approach remained viable in a whole range of situations where it is necessary to have a fast and easy-to-manage database. This contribution starts from the hypothesis that an offline standardised and encapsulated tool

in an open format (such as SQLite, LibreOffice Base or MySQL), editable with open source software, can offer additional solution because it is easy to use and disseminate in the form of a free, downloadable template. EMdb aims to collect and manage not only stratigraphic data but also reconstructive unit sheets to cover the need to analyse, interpret and validate scientific hypotheses in the field.

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# IL CONTESTO URBANO DEL TEATRO ROMANO E L'AREA DELL'EX FILANDA BOSONE A FANO (PU)

## 1. L'indagine archeologica

Agli inizi del 2021 l'amministrazione del Comune di Fano ha avviato un primo intervento di indagine archeologica stratigrafica all'interno dell'area dell'ex Filanda Bosone, nel centro storico, nel luogo in cui anni addietro erano stati scoperti casualmente i resti del teatro romano, con l'intento di valorizzare e rendere fruibile l'area e con l'idea progettuale di andare a raccordare questi resti con l'area archeologica del cosiddetto Tempio della Fortuna presente sotto il complesso di Sant'Agostino (Purcaro *et al.* 2013). La direzione scientifica dell'intervento è stata svolta dalla Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Ancona e Pesaro.

L'indagine archeologica si colloca all'interno dell'area forense della *Colonia Iulia Fanestris* (Milesi 1992), tra il teatro romano a O e il complesso tempio-criptoportico a E (Fig. 1). Per indagare le varie possibilità progettuali si è deciso di intervenire non direttamente nel teatro, oggetto di scavo stratigrafico tra il 2001 e il 2006 (Baldelli 2002), ma all'interno degli edifici della filanda, per poter mettere in connessione quest'area con i resti archeologici presenti sotto il complesso di Sant'Agostino, oggetto di scavi ottocenteschi non condotti mediante metodo stratigrafico. Nel complesso, l'intervento archeologico ha visto l'esecuzione di due saggi di dimensioni contenute, realizzati l'uno (Saggio H) all'interno dello stabile più recente della filanda e l'altro (Saggio I) tra i due corpi della fabbrica. Un terzo e più ampio sondaggio (Saggio L) è stato condotto all'interno dell'edificio più antico, partendo dal limite meridionale di un sondaggio archeologico realizzato nel 2006 e procedendo verso SO (Fig. 2).

A conclusione dello scavo in programma, si è tentato di riaprire mediante mezzo meccanico uno dei saggi effettuati nell'area nel 2006, per cercare di arrivare ai piani individuati durante la campagna di scavi pregressa, ma il tentativo non è andato a buon fine, a causa di problemi di sicurezza e stabilità delle pareti del sondaggio. Tuttavia, è stato possibile, confermare la presenza di consistenti interventi antropici di spoliazione che hanno asportato completamente due delle strutture murarie che componevano il lato O del criptoportico di epoca romana, già individuato nel suo lato orientale al di sotto della Chiesa di S. Agostino (Volpe 2013).

L'indagine archeologica ha messo in luce una sequenza stratigrafica complessa e articolata, estesa tra la prima età imperiale (fine I secolo a.C.), epoca in cui si colloca la costruzione dell'edificio religioso, più volte identificato

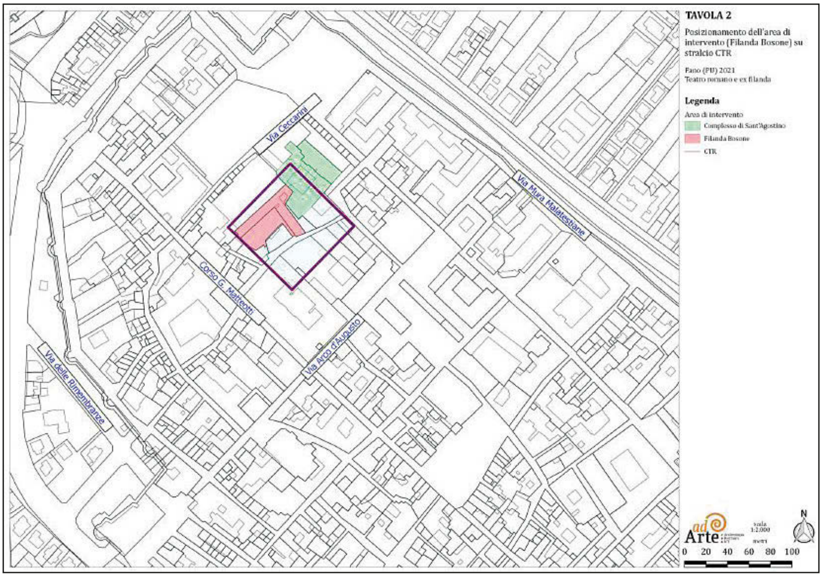


Fig. 1 – L'area di intervento.

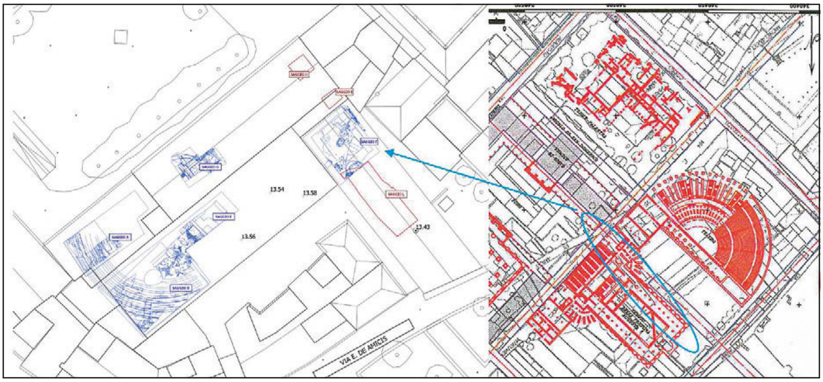


Fig. 2 – I sondaggi archeologici.

con il cosiddetto Tempio della Fortuna, e l'età contemporanea, in cui l'area ha accolto una fabbrica manifatturiera per la produzione di seta, poi trasformata nel secondo dopoguerra in maglificio. I saggi I e L hanno restituito gli importanti resti, in ottimo stato di conservazione, del corridoio coperto che consentiva l'accesso laterale alla grande struttura templare, posta ad E e orientata NE/SO. Nel complesso la struttura era chiusa lungo il lato orientale

Fig. 3 – I setti murari del criptoportico.

da un grande muro, scandito da lesene e finestre strombate, individuato in minima parte all'interno del Saggio I, e da un sistema di setti radiali e pilastri, che sorreggevano volte, rinvenuto nel Saggio L all'interno del corpo più antico della fabbrica (Fig. 3). Tutti gli alzati, che svettano per un'altezza massima di 3,80 m, sono in opera vittata, con nucleo cementizio realizzato mediante messa in opera di malta, pietre e ciottoli, rivestito da blocchetti rettangolari in pietra arenaria, sistemati in filari orizzontali perfettamente allineati e regolari.

Intorno alla metà del I secolo d.C., forse a causa di una calamità naturale, si assiste ad un primo intervento di restauro strutturale e sistemazione dell'area e il piano pavimentale viene rialzato di circa 50 cm. Verso la fine del III secolo, forse a causa delle prime incursioni barbariche e della crisi politico-economica che attraversò l'Impero tra la fine del III e il VI secolo d.C., l'edificio subisce un primo consistente intervento di spoliazione e registra il crollo di alcune strutture, tra cui anche quello delle volte di copertura del criptoportico. In epoca tardo antica, si assiste al livellamento dei crolli strutturali e alla rioccupazione dell'area mediante risistemazione degli ambienti con probabile cambio di destinazione d'uso. Non è da escludere che l'area sia stata riadattata e utilizzata come fortilizio durante il conflitto greco-gotico (535-553 d.C.). In quest'epoca vengono ricavati nuovi ambienti mediante la costruzione di alcuni muri perpendicolari ai setti radiali di epoca imperiale e dunque, alla chiusura dell'area verso O. Queste nuove strutture presentano gli alzati realizzati con materiale di recupero legato da sabbia poco coesa. In età medievale, senza soluzione di continuità, avviene una nuova e importante fase di occupazione del luogo, con piani di calpestio e la costruzione di una fornace.

L'utilizzo dell'area ad uso produttivo potrebbe essere ricondotto ad attività secondarie svolte in alcuni ambienti di servizio annessi agli edifici pubblici (*Palacius Maius* o *Vetus*) costruiti a partire dall'età carolingia nell'area dell'arena (teatro romano), in cui è attestata anche una chiesa di *S. Johannes in Palacio* e una Platea de Rena (Frenquellucci 2002).

Alla fine del Medioevo si assiste all'abbandono definitivo, quando l'intera area viene destinata ad orti e campi, come testimoniato dalle cartografie moderne. Nelle piante redatte tra il 1840-1842, anni in cui nell'adiacente complesso di Sant'Agostino si svolgono i primi scavi archeologici, l'area è indicata con i toponimi Orto Maccheroni e Orti del Seminario e tale rimarrà fino a qualche decennio più tardi, quando ospiterà la fabbrica della filanda del sig. Carlo Bosone, detto "el milanes".

## 2. La documentazione con pyArchInit

Contestualmente alle operazioni di scavo stratigrafico, si è proceduto con la documentazione delle evidenze riscontrate, elaborata digitalmente e direttamente *in loco*, utilizzando l'applicativo pyArchInit, installato come plugin sulla piattaforma open source QGIS (Mandolesi 2009; Mandolesi, Cocca 2013). Sono stati inseriti tutti i dati desunti dal contesto archeologico in corso di scavo all'interno delle varie tabelle, alfanumeriche e geometriche, presenti nel database, utilizzando direttamente una serie di interfacce grafiche offerte dal plugin, corredate da layer per la localizzazione del dato georeferenziato. In QGIS si è proceduto con la creazione di un database spatiaLite *ad hoc*, denominato Fano_(PU)_Teatro_romano.sqlite, per poi avviare tutta la gestione del dato archeologico sul plugin, iniziando dalla creazione di una scheda di sito con la denominazione ufficiale: Fano (PU) ex Filanda.

Direttamente dall'interfaccia grafica della scheda di sito è stato possibile generare le schede relative alle unità stratigrafiche (US) e a quelle murarie (USM), elaborate sul modello di quelle ministeriali emesse dall'Istituto Centrale per il Catalogo e la Documentazione (ICCD). In base alle informazioni inserite nei campi di definizione stratigrafica, e tramite la creazione di uno stile per tipologia di strato, la restituzione grafica dei singoli strati è risultata immediatamente caratterizzata in base alla definizione stratigrafica e/o a quella interpretativa (Fig. 4). In fase di elaborazione cronologica dei dati archeologici, sono state sfruttate le potenzialità di varie funzioni presenti nelle schede US, che vanno ad automatizzare alcune delle operazioni, aumentando il controllo sull'integrità del dato e la validità dell'output e che, quindi, consentono di ottimizzare notevolmente risorse e tempi di scavo. Tra queste

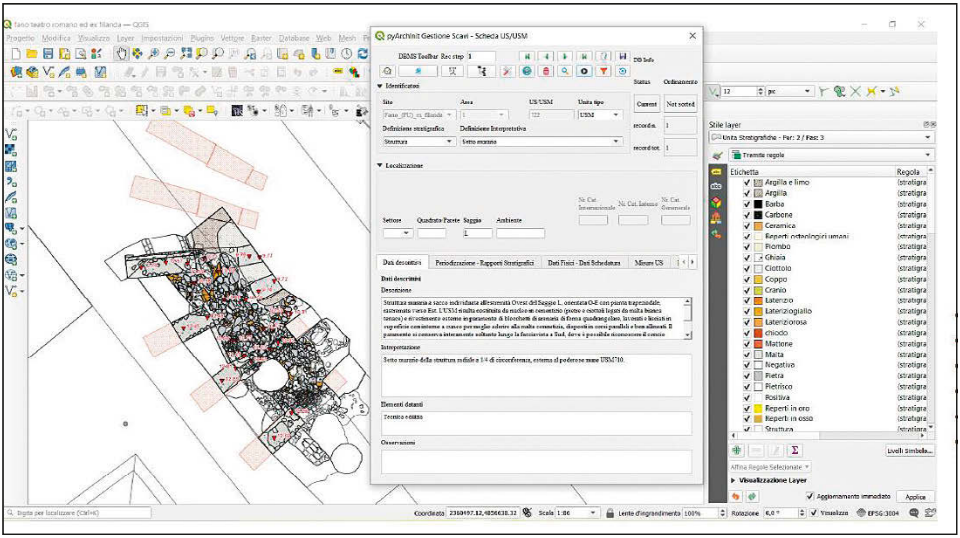

Fig. 4 – Le schede di unità stratigrafica in pyArchInit.

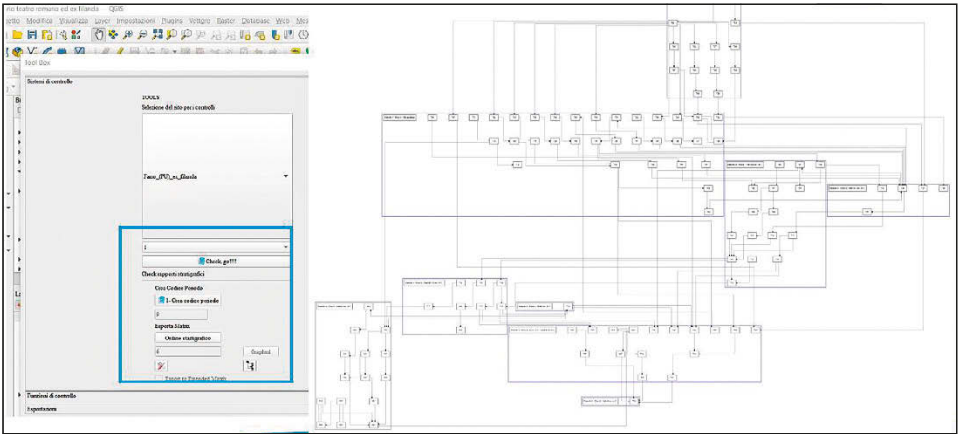

Fig. 5 – Controllo stratigrafico ed esportazione del matrix.

funzioni, si è rivelata molto utile, e in alcuni casi risolutiva, quella relativa al controllo automatico dei rapporti stratigrafici, o la generazione dei codici di periodo o, ancora, l'esportazione del diagramma stratigrafico (matrix) con il dettaglio delle fasi cronologiche (Fig. 5).

Per quanto concerne la sistemazione e la catalogazione dei dati antropici materiali, sono state utilizzate le tabelle dedicate ai reperti archeologici notevoli (RA 1-38), denominate scheda reperto, con i riferimenti stratigrafici, la classificazione tipologica e morfologica, la descrizione generale e altri riferimenti fisici rilevati in fase di schedatura; allo stesso modo sono stati catalogati anche i campioni (nn. 1-7) recuperati durante le indagini. Sono state altresì schedate singolarmente le strutture individuate nel contesto di scavo, ovvero il criptoportico (CRP), il focolare (FOC) e la fornace (FOR), i singoli periodi e le fasi cronologiche in cui si sviluppa la successione stratigrafica indagata.

Una volta completato l'inserimento di tutti i dati di scavo, è stato possibile generare, in maniera automatica, non solo le piante delle singole unità stratigrafiche, ma anche quelle di fase e di periodo, corredate dalle quote altimetriche, e avere l'esportazione dei file PDF in formato ministeriale di tutte le schede singole (schede US, schede periodo, schede struttura, schede reperti, schede campioni), dei vari elenchi e del già menzionato diagramma stratigrafico (matrix).

A conclusione del lavoro di documentazione insieme alla relazione finale dell'indagine archeologica condotta è stato possibile consegnare alla Soprintendenza di riferimento l'intero pacchetto dei layers informativi georeferiti nel sistema Gauss Boaga Est (EPSG 3004), facilmente interfacciabili con i vari Sistemi Informativi Territoriali pubblici.

## 3. Dallo scavo alla pianificazione territoriale

Utilizzando questo software di gestione, è possibile avere in un'unica piattaforma tutte le ricerche svolte, dalle ricognizioni di superficie agli scavi archeologici, naturalmente con la possibilità di eseguire letture incrociate e trasversali e, dunque, fare query di ogni tipo e gestire facilmente i dati archeologici di uno o più contesti indagati. Lo stesso è auspicabile a livello macroscopico, all'interno delle soprintendenze e degli enti pubblici, in quanto tutto il pacchetto fornito può facilmente confluire nelle banche dati dei sistemi utilizzati per la catalogazione e la gestione dei beni culturali, come il SI.R.PA.C. (Sistema Informativo Regionale del Patrimonio Culturale) e il SIGECweb, attualmente alla base della Carta Archeologica delle Marche (C.A.M.), o per i sistemi di archiviazione e tutela adoperati a livello regionale e nazionale come RAPTOR (Frassine, De Francesco, Zambetti 2021) per le regioni del Nord Italia, o l'applicativo di nuova generazione adoperato dalla Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Ravenna, Forlì-Cesena e Rimini (ARCHEODB), anche in vista dell'applicazione delle nuove linee guida ministeriali per l'archeologia preventiva fornite dall'Istituto Centrale per l'Archeologia, approvate con il Decreto del Presidente del Consiglio dei Ministri del 14 febbraio 2022 (pubblicato in Gazzetta Ufficiale n. 88 del 14 aprile 2022).

Un aspetto da tenere in considerazione è la versatilità di questi dati informativi per la gestione e la pianificazione urbanistica ad opera degli enti territoriali, per l'elaborazione delle Carte di Potenzialità Archeologica, per l'aggiornamento dei Piani Regolatori Generali e degli altri strumenti di pianificazione dettati dalla nuova disciplina urbanistica, come il Piano Strutturale Comunale Associato (PSCA) o il Regolamento Urbanistico ed Edilizio (RUE), e naturalmente, per la realizzazione dei geo portali cartografici su base GIS disponibili in rete.

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ABSTRACT

This paper illustrates the usage and potential of the pyArchInit plugin, an open source tool created in Python language for the management and overall analysis of archaeological data on a single georeferenced platform (QGIS). Some of the functionalities of the application are highlighted in relation to the archaeological survey conducted in 2021 within the area of the Roman theater and the former Bosone spinning mill, in the historic center of Fano (PU), in

the Marche region. Specifically, at the same time as the stratigraphic archaeological excavation operations were carried out, we proceeded directly on site, with the detailed management of both the identified stratigraphic Units and the finds recovered during the excavation, with direct data entry. In this way, it was possible to deliver to the Superintendence all georeferenced information layers in Gauss Boaga Est (EPSG3004) reference system, manageable in different GIS platforms and easily usable as a scientific research instrument for protection and planning of cultural heritage.

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# PYARCHINIT AT CASTELSEPRIO: PROGRESSIVE ADOPTION OF AN INTEGRATED MANAGING SYSTEM FOR ARCHAEOLOGICAL FIELD DATA

## 1. Introduction

This paper explores the adoption of pyArchInit as a tool for managing field data in the investigation of Casa Torre, Castelseprio (VA) (La Salvia *et al.* 2022). The topic will be tackled from a teaching/training perspective, focused on a small team of students and in the framework of a research/training excavation. The use of digital tools for the management of archaeological field data is nowadays a standard practice. Being primarily spatial and alphanumeric data, GIS has a long tradition of being used for mapping and/or recording archaeological evidence and many proprietary and open applications have been built for this purpose (such as iDig, Archtools, OpenDig and many others, see Doneus *et al.* 2022; Psarros, Stamatopoulos, Anagnostopoulos 2022). In the last two decades, the needs of archaeologists shifted from simple 2D shapes and simple local databases, to 3D imaging, LiDAR, UAS imagery as well as multiuser remote databases, Big Data analysis and so on.

M.M.

## 2. The context of Casa Piccoli (Castelseprio, Va) between research, training and public archaeology

The use of traditional documentation systems (i.e. paper) has long since begun to show its operational limits. We all know that archaeology produces an enormous amount of evidence that often has to be translated into a written record, the compilation of which, besides being time-consuming and laborious, is frequently subject to a high percentage of inhomogeneity and errors. Fully mastering such a wealth of information generally turns into an arduous, if not impossible task, especially when it has to be fully processed (to transform it into a historiographical model). On the contrary, the use of the IT tool allows for a much more effective and versatile archaeological record's archive. Moreover, it makes it possible to implement strict quality controls at the data entry level and to perform a wide range of analyses at the interpretation stage (statistical, spatial, logical, data managing), providing new opportunities for achieving greater flexibility than the paper-based record. It is precisely these two aspects, on both the managerial and the

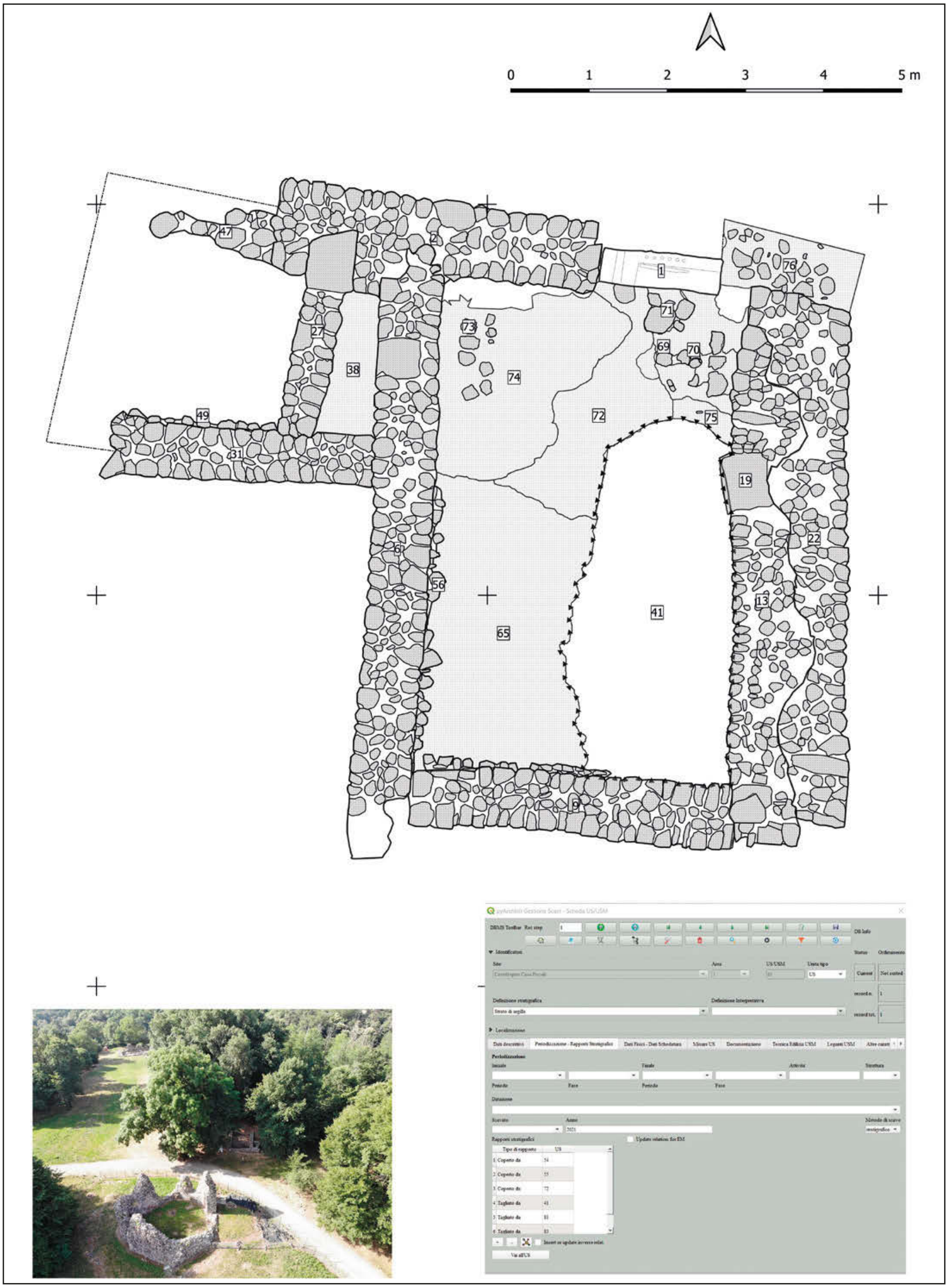


Fig. 1 – Excavation at Casa Piccoli, Castelseprio: pyArchInit US vectors and database.

analytical level, that most clearly are showing the qualitative increase that digital technology has brought to archaeological research.

This is particularly true in cases such as that of Casa Piccoli excavation (Fig. 1), where the need to document a complex stratification (early medieval layers, features of dismantled metal workshops) has to be combined with that to build a record appropriate to both didactic-formative and dissemination aspects (i.e. Public Archaeology), the site being located within an Archaeological Park. Digital archaeology and data management are fundamental and mandatory to have a continuous overview of the investigation area; to update the data and be able to query it, facilitating the data validation process; for cross-referencing data; for creating an open and public scientific and scholarly environment. However, in order for technology to truly assume a transformative role within the research project, it deserves to be used with awareness and full knowledge of the real capabilities of the tools.

The researcher should be able to choose for the most suitable type of hardware and software environment, depending on the purposes of the research project, the shape of information that has to be supported and the type of processing data that is to be implemented. Above all, it is necessary for the archaeologist to be able to determine how the information and the analyses of the data are to be managed by the computer. The tool-building process, in fact, has to be centered on the elaboration of a data modelling process: this represents, in the analysis of an IT solution, the moment of closest involvement of the archaeologist's own "cognitive process". The accuracy of the information recorded and the possibility of producing knowledge through the use of digital technology largely depends on it. In fact, if archaeology still stands in the field of Humanities, aiming to increase historical knowledge through the use of material evidence, information technology applied to archaeology should be understood as a set of methodological and technical tools only for the elaboration of historical models.

The possibilities offered by digital technology are perfectly suited to the purpose: they allow large quantities of data to be managed, disseminated and shared. Such a possibility opens up entirely new perspectives in the field of archaeological research, potentially making a vast collection of information available to the entire scientific community, online and in real time. The benefits deriving from this approach range from the search for comparisons to the contextualisation of data, from the possibilities of performing quantitative analyses to cross-checking the quality of information and processing and managing data (Fronza, Nardini, Valenti 2009; Montagnetti, Mandolesi 2019).

V.L.S.

## 3. pyArchInit in practice: a 3-year program

In the choice of a digital tool for recording the archaeological evidence in our excavation, there were some requirements to be met. The first requirement was related to the Italian law on research excavations. The archaeological excavation at Casa Piccoli, Castelseprio is carried out under the license of the Ministry of Cultural Heritage (ref. 631/ 23-05-2022). Current regulations from the Ministry of Cultural Heritage require the delivery of the site plans and topographic position in a vector format, specifically shapefiles SHP, Geopackage GPKG or DXF. Therefore there was a need of GIS software, at least for the final delivery of documentation. The second requirement was to be open (open as open source archaeology and open archaeology: Wilson, Edwards 2015; Marwick 2017) and integrated with the tools we already use, specifically QGIS. The "openess" affects not only the data but also the students involved in the excavation.

Being a university training excavation, it is aimed at teaching students the necessary skills to work in the field. The batch of students working in our excavation is highly trained (4-6 months of previous experience with fieldwork), already exposed to GIS use, even if in a very basic form. This training aspect is very important when you take into consideration which tool or software will be used in a research/training excavation. Two topics, in particular, were crucial in our choice. The first topic is the restricted amount of time available to students for training and practicing the tool/software. Students are usually trained on the go during the excavation or, more rarely, just after the excavation when the lab activities take place. Due to deadlines, exams and courses, the time dedicated for these activities is always short. A second and perhaps even more important topic is sustainability. Training in excavations and lab activities is fundamental to develop skills for the job market. When a student graduates in Archaeology, he is supposed to know not only how to dig or how to correctly draw a potsherd, but also how to manage digital archaeological data, like site plans, aerial photographs, drawings, 3D models and so on.

Therefore we argue that teaching through FLOSS software (such as QGIS and pyArchInit) is ethically correct as they are available for everybody to use and economically sustainable in the framework of soon-to-be professionals. PyArchInit met all the requirements we had, being FLOSS software and specific for the digital management of an excavation. The software, developed since 2009 by L. Mandolesi and E. Cocca (Mandolesi 2009; Mandolesi, Cocca 2013; Montagnetti, Mandolesi 2019; Mandolesi, Montagnetti, Pickel 2022) is a plugin for QGIS, meaning that there was no need for an external software and the main commands were already

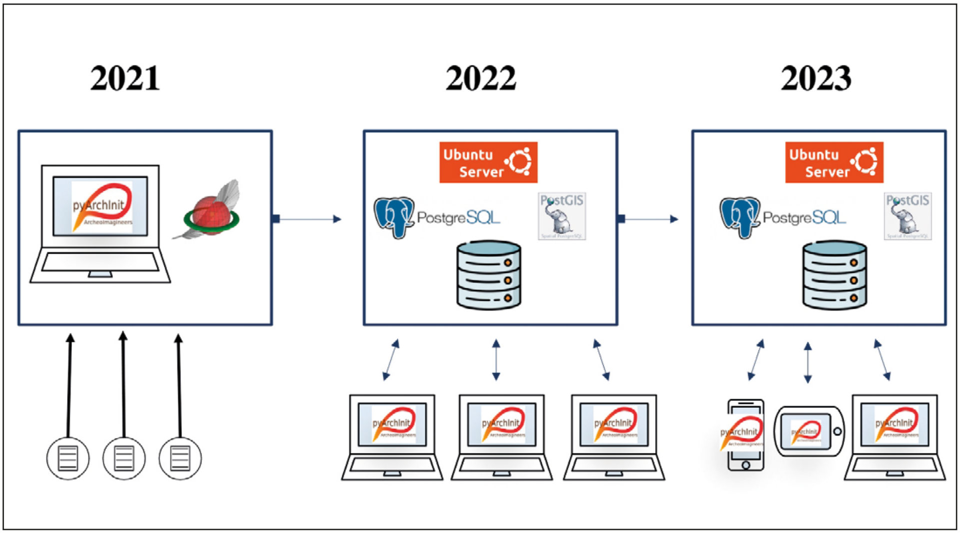


Fig. 2 – Graphical schema of the 3-year implementation program.

known by the students. Quoting the developers, in fact, «pyArchInit has been created by archaeologists, and it caters to specific archeology needs. It provides dedicated tools that allow archaeologists to upload and check all the digital survey information taken and all the alphanumeric documentation (paperwork) produced during an archaeological project» (Montagnetti, Mandolesi 2019, 32). PyArchInit includes a range of features, such as the ability to create detailed site reports, generate maps and plans of excavation sites, and manage artifacts. One of the key advantages of pyArchInit is its ability to handle large amounts of data efficiently and accurately. Also, being integrated in QGIS, it works in an environment which provides a powerful tool for digitizing vector data and georeferencing raster plans, as well as a database tool to manage Stratigraphic Unit sheets, etc. One issue that has been personally faced with the software is its learning curve, which may require many hours of application especially if one tries to master the software all at once.

Building on previous experience in using the software, it was planned to implement it with a gradual transition from a traditional full paper documentation to a fully digital one (Fig. 2). There was no previous documentation to acquire, since the excavation started from scratch; this gave us also the opportunity to gradually increase the complexity of the infrastructure in use, shifting from local to remote. This was meant not only to understand the capabilities offered by the software but also to evaluate in person how difficult and how much expensive it is. This former aspect should not be taken lightly from the point of view of a soon-to-be professional. The implementation program covers the years 2021-2023 (Tab. 1).

| | Nr. of Students | Focus | Activities |
|---|---|---|---|
| 2021 | 6 (MA candidates with preliminary training) | Local; Spatialite; Data Recording; Single user, tasks divided by team | Paper documentation on field, Digital in lab |
| 2022 | 7(6MA candidates + 1 Postgraduate) | Server; Remote; Data Recording, Elaborating; Multi-User; task shared by team | Paper and Digital documentation on field |
| 2023 | 10 (foreseen) | Resolve Issues; Raster Data; Mobile | Workflow setup<br>Mobile data entry |

Tab. 1 – 3-years implementation program.

For 2021 excavation a new project was created on a main machine with a local, single user Spatialite database. During the archaeological investigation, paper stratigraphic unit sheets (SUs) were used to record data and UAV pictures and Structure from Motion of Casa Piccoli to survey archaeological features. Later in the lab, the students were divided into small teams and were assigned a specific task: team A to fill SUs in the database, team B to take inventory of the artifacts and team C to map SUs on georeferenced orthophotos. The result of the first year was that six students were involved in this field training. They were all MA candidates and they already had some excavation experience. As a result of the 2021 campaign, we compiled 75 SUs, 50 artifacts in the inventory and drew over 1000 vector shapes, taking 4 weeks of work, of which 2 on field and 2 in lab, dedicated especially to the yearly report due to the Ministry of Culture.

The transition to the second year 2022 was instead focused on shifting on a multiuser, remote approach. Before the excavation, a server was assembled re-using an old desktop PC (i7, 12Gb Ram, 1 Tb SSD) running Ubuntu Server and hosting a PostgreSQL Server with PostGIS extension. A collateral goal was to judge, even in a subjective way, how difficult it was to set up such a machine and also to reuse an old PC to save money. Data from 2021 was then uploaded to the new server. Students were still asked to compile both digital and physical SUs and artifact inventories, but this time every student accessed the data directly on the server and everything was digitized into the remote database. Also, instead of teams dedicated to specific tasks, everyone worked on different parts of documentation. By the end of 2022, the PostgreSQL database hosted 100 SUs, more than 70 artifact items and over 1900 vector shapes. It must be noted that currently only vector data are uploaded to the server, while raster data, such as orthophotos are still on local machines.

The third year 2023 foresees the stabilization of the remote server protocols and workflow, addressing all the issues encountered previously (see below the SWOT analysis), as well as experimenting with digital recording in the fieldwork, possibly through mobile applications (i.e Qfield). Also the focus will be more on data elaboration and specifically on the implementation of structures and phases to build period plans.

## 4. Discussion-SWOT analysis

After two years of implementation, it was decided to run a SWOT analysis: while the primary goal of SWOT analysis is to increase awareness of the factors that go into making a business decision or establishing a business strategy, here is intended to evaluate the combination between the implementation strategy and the software more than the software itself. In terms of strong points, the team's feedback on the software was generally positive. It was found that, due to the detail in the data entry masks, single persons or teams dedicated to specific tasks (SUs, artifacts, drawing) were more effective than everyone working on every part. Moreover, if different users did not overlap, the same table wasn't accessed in the same moment by two users, making it easier to control the read/write data activity and avoiding locks and data being unintentionally deleted.

The accessibility of the documentation without paper and the possibility to work almost on the field was another positive side of the implementation of pyArchInit. As for what concerns workload and learning curve, the progressive integration between physical/digital and local/remote was acceptable: despite the time dedicated to training being short, the students grasped the basic skills of data entry and how specific sheets needed to be filled. In addition, the cost sustained to build and start the server was almost none, since it was an old machine running FLOSS software. At the moment, in fact, the computing power required to run pyArchInit on remote is not high, but it must be taken into consideration that only vector data (generally lighter than rasters) are uploaded. Finally, pyArchInit is already set for the output of the documentation along the guidelines required by the Ministry of Culture, speeding up the process of the composition of the final reports.

From the point of the user experience, one of the elements that emerged as problematic is the way some of the forms are designed. SUs and artifact sheets are very detailed and visually different from the physical ones, which usually the students are more familiar with. The sheet structure is a bit labyrinthic; many fields are stacked together and it makes data entry harder on small screen laptops. Another issue regarding data entry: in uploading tables from the local Spatialite database to the PostgreSQL server, often the process was stuck in an error due to the different length of data formats between the two databases.

Considering the different opportunities offered by the software, it must be noted that while at the moment pyArchInit works well in a desktop environment, the possibility to manage data directly from smartphones and tablets can really increase the software usability. Mobile batteries in general tend to last longer than laptops, they are usually handheld and incorporate a (generally good) camera and an Internet connection, making them perfect for fieldwork documentation such as compiling SUs. In the last months several regular updates enhanced the user experience and added useful tools such as a way to directly upload total station points. The crucial opportunity in pyArchInit is, as in every open software, the possibility to actively contribute to the software development. This contribution can be in the form of identifying and reporting bug and issues to the GitHub, suggesting new features to be implemented or contribute with new code, UI design, writing documentation and so on. As a result, it is also possible to develop pieces of software specific to one's needs that will also be available for other people to use, debug, enhance and so on. In this framework, the issues noted in this SWOT analysis are also a contribution of sort.

The first threat concerns specifically the excavation in Castelseprio but it is relatable to different contexts as well. In the framework of a fully digital multi-user workflow centered on pyArchInit, Internet connection becomes crucial. Around Casa Piccoli, mobile signal is weak and generally Castelseprio is not very well served by the Internet connection, which slows down work and asks for hybrid temporary solutions (such as coming back to 2021 workflow).

## 5. Conclusion

GIS applications have become the norm in archeological documentation; open source solutions from the mid '90 rose in number, opening new possibilities both for recording and elaborating archaeological data (Ullah, Clow, Meling 2023). PyArchInit finds its place in this framework, offering the only (to our knowledge) complete solution to handle stratigraphic data within a GIS open source environment. Overall, the implementation resulted in the development of a new workflow for our excavation, which produced a good outcome both in terms of data recording and students training.

M.M.

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## ABSTRACT

In the framework of the project 'Castelseprio, centre of power', the authors began excavating the structure known as Casa Piccoli in 2021. The area, already investigated by Piccoli in the 1970s, presents itself as an interesting case study for the application of an open and integrated solution for the management of stratigraphic data, specifically pyArchInit. Being an academic excavation project and, therefore, characterized by both research and training issues, it was decided to progressively and incrementally include the use of pyArchInit within the documentation protocols on site and post-excavation, over the three years of the permit granted by the Ministry of Culture for the excavations. Master's degree students who participated in the excavation, at the end of the planned period, will

have the basic skills to use the plugin also in a professional environment. At the end of the first two years of implementation, a SWOT analysis will show the results obtained within the site for both training and research purposes.

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# MASPAG & PYARCHINIT, THE NEWBORN COLLABORATION OF SAPIENZA AND ADARTE IN THE SULTANATE OF OMAN

## 1. Introduction

MASPAG, which stands for Missione Archeologica della Sapienza nella Penisola Arabica e nel Golfo (Archaeological Expedition of Sapienza in the Arabian Peninsula and the Gulf), is a new multidisciplinary archaeological project financed by Sapienza Great Athenaeum Excavation program since 2019 (Ramazzotti 2021a), recognized and supported by Italian Ministry of Foreign Affairs and International Cooperation since 2022. The project focuses on the Italian long-lasting archaeological tradition of research in Western Asia, in the South-Eastern Arabian Peninsula and especially in the Sultanate of Oman (Frenez, Cattani 2019). MASPAG aims to study the ways of life of the ancient communities that inhabited the Arabian Peninsula and the Gulf, which were in direct contact with the most renowned ancient empires (Ramazzotti 2022). Indeed, Ancient Eastern Arabia became the framework of a unique development of social relationships, based on tribal alliances and human mobility rather than kingship and bureaucracy (Tosi 1986; Cleuziou 2009; Bortolini, Tosi 2011).

Field activities focus on the conclusion of the stratigraphic investigation of the large collective burial LCG-2 in the monumental funerary complex of Daba al-Bayah, in the governorate of Musandam, Sultanate of Oman (Genchi 2019, 2020; Genchi *et al.* 2018, 2022; De Cataldo *et al.* 2020). In 2021, the Sapienza archaeological mission decided to extend its archaeological investigation by setting the foundations for a new landscape investigation project, in agreement with the Ministry of Heritage and Tourism of the Sultanate of Oman and the Italian Ministry of Foreign Affairs. The first step was to identify the survey area, which had to meet certain logistical as well as scientific requirements. Clearly, the first and fundamental point was the absence of pre-existing archaeological investigations or activities, in order to have an unexplored landscape to document and study, a georeferenced ecotope to analyse through computational and digital modelling as an Artificial Adaptive System (Ramazzotti 2014, 2021b; Ramazzotti *et al.* 2020).

Located in the al Batinah South Governorate of Oman, in the provinces of Nakhal, al-Awabi and Wadi al-Ma'awil (Fig. 1), the surveyed area offered the ideal context to start a new landscape project, which would lead to explore the complexity of human mobility and social organisations at the core of the so-called Land of Magan (Potts 2000). The geomatic mapping of the archaeological landscape was structured in two main operations. First, an in-depth

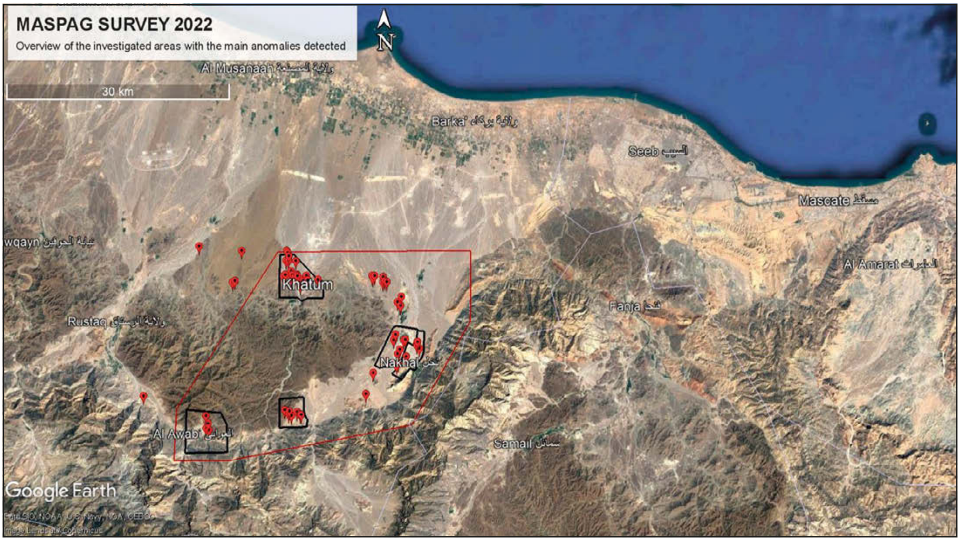


Fig. 1 – Overview of the investigated area.

remote-sensed based examination of satellite images of the area was carried out, with the aim of recognising anomalies or rather clusters of anomalies that could indicate the presence of archaeological areas (November 2021-January 2022).

The analysis of satellite images by Google Earth Pro has proven its effectiveness in landscape archaeology and this approach has also been proposed in Oman, particularly in the framework of the Wadi Andam archaeological project (al-Jahwari, Kennet 2010; Deadman 2012a). The absence of pre-existing works on the selected area made the remote sensing approach the first step in discovering and understanding the survey landscape. Before starting the satellite survey, the literature was reviewed to identify and classify the specific morphologies of archaeological features in the Omani landscape (Giraud, Cleuziou 2009; Deadman 2012b; Condoluci, Esposti, Phillips 2014; Thornton, Cable, Possehl 2016; Döpper 2018; Döpper, Schmidt 2020; Düring 2022; Swerida 2022).

By examining the historical images, it was possible to observe the archaeological evidence before and after the excavation activities, recognising how they appear in the pristine landscape. In this way, the morphologies and positioning of the major archaeological features in the landscape were identified, so that they could be pinpointed as anomalies and anomalies' clusters to be verified on site. Once the most promising areas were identified, fieldwork was initiated for ground verification of the anomalies and for the documentation of the landscape (February 2022).

The aim was to highlight the archaeological potential of the area and to set up a remote sensing and ground truthing methodology by integrating the analysis of satellite images with targeted field surveys. Exploiting the potential offered by modern application of remote sensing and Geographical Information Systems (Ramazzotti 2013a, 2013b; Casana 2020; Montagnetti, Guarino 2021), an unexplored multi-millennial landscape was charted, highlighting the relationship with the high density and variability of archaeological features and modern anthropic activities.

Approaching a landscape yet undocumented by scientific literature, one of the ambitions of the survey was to create a cartographic basis for future exploration and to define a workflow protocol for the documentation of all archaeological data. For these reasons, and in anticipation of the opening of stratigraphic excavations, new possible GIS solutions were researched with the aim of developing a comprehensive documentation management system. The exploration of these solutions was the drive and meeting point between MASPAG and pyArchInit.

## 2. Objectives

The collaboration between MASPAG and adArte srl (developer of pyArchInit, see below) was founded with a clear objective: to digitally enhance the archaeological documentation apparatus of the archaeological field activities of Sapienza in the Sultanate of Oman. This intent took the form of a PhD student application for funding from Sapienza University of Rome for Research Initiation Projects (Progetti per Avvio alla Ricerca - Tipo 1). The proposal had as its objective the development, in collaboration with dedicated programmers, of a geodatabase to manage information and data of the archaeological landscape of MASPAG's area of interest.

Involving experienced professionals in both standardised computer language for relational databases (Structured Query Language, SQL) and sciences of antiquities would have allowed the creation of a highly performing dedicated product, optimising research time and promoting a metadisciplinary approach that could become the basis for future research and collaborations. This project would also make it possible to create an online platform to which the raw geographical and archaeological data of other research groups active in the area could be redirected, projecting towards dissemination in Open Access format and research communication.

The funding of the Sapienza's Research Initiation Project made it possible to institutionally start the collaboration between MASPAG and the developers of pyArchInit open sources plugin for QGIS (Mandolesi 2009; Mandolesi, Cocca 2013; Cocca, Mandolesi 2016; Montagnetti, Mandolesi 2019). As a first step, it was mandatory to clarify the objectives in order to plan a strategy to achieve them and overcome the main challenges, thus an early assessment was necessary. The project "pyArchInit - Open Source Platform for Archaeology" (https://pyarchinit.org/), is being developed since 2005 with the purpose of building a Python plugin for the open source software QGIS, specifically for the management of archaeological data (Mandolesi 2009).

Over time, pyArchInit has become a working and interaction model, a sequence of procedures that are gradually being developed and codified in order to achieve real data management in both research and heritage preservation (Mandolesi, Cocca 2013; Guarino, Rosati 2021). In its current state, the plugin workflow allows maximum portability and compatibility of the system, and the complete management of stratigraphic data and archaeological and anthropological materials, by systematically integrating and putting together alphanumeric cartographic and multimedia data (Montagnetti, Mandolesi 2019).

Given these premises, the potential of adopting the plugin in MASPAG's documentation system was obvious: to obtain an archaeological specific geodatabase documentation platform with a clearly operational workflow and a direct contact with its developers, themselves being professional archaeologists. Only one element had to be developed and integrated into the system to precisely answer the proposal presented in the Research Initiation Project, and thus meeting the scientific expectation of MASPAG: the archaeological landscape, its decomposition and documentation.

Pointing out the need to expand the existing pyArchInit system was extremely well received by its developers, embracing the principle of keeping the system always open for adding new features and functionalities (Mandolesi 2009, 209-210). The foundations were laid for a long-lasting partnership across multiple topics and branches of archaeological research: training in the management of geo databases and advanced use of GIS for archaeology with pyArchInit, the development of a dedicated geodatabase platform for the documentation of the archaeological landscape and its issues, challenges and stakes.

The ultimate long-term goal we expect to achieve in the next years is the development of an open source GIS solution for archaeological investigation, from stratigraphy to landscape, integrating the structure developed for the MASPAG 2022 survey within the pyArchInit system. Achieving these ambitions will lead to a twofold objective: the developer team by adArte will be able to extend the reach of the pyArchInit platform with a landscape documentation tool, while at the same time, the Sapienza team will have the pyArchInit platform available for all scientific documentation, from survey to excavation.

## 3. First results

The last year saw the first results of the newborn collaboration between Sapienza and adArte: advanced training in the management and use of geodatabase in a GIS environment (QGIS and pyArchInit), and the development and field application of a dedicated structure for documenting the MASPAG survey. The training, financed by Sapienza Great Excavation to adArte, included a 24-hour course in October 2021 covering the theoretical and practical aspects of building, managing and applying geodatabases (mainly Spatialite and PostgresSQL). Specific classes followed on the use of the pyArchInit plugin: installation on QGIS and the organisation of datasets; digitisation of stratigraphic units (SU), plans and sections; management of stratigraphic relationships and Harris matrix generation; export of phase plans, cards and lists for SU and archaeological materials.

The result of this phase was the development of the relational geodatabase structure on QGIS for the documentation of the first survey season planned for February 2022. The aim is to fully integrate into the pyArchInit system this beta version, which was positively tested by the survey team (Mandolesi 2009, 212-213). The entities of the archaeological survey were separated (transects, collection areas, archaeological features, view points) and associated with geographical and environmental features and entities (provinces, land use, topographical units, building sites) (Montagnetti, Mandolesi 2019).

The core element of the system is the relationship between Topographical Unit (TU) and archaeological features (documented and digitised as points,

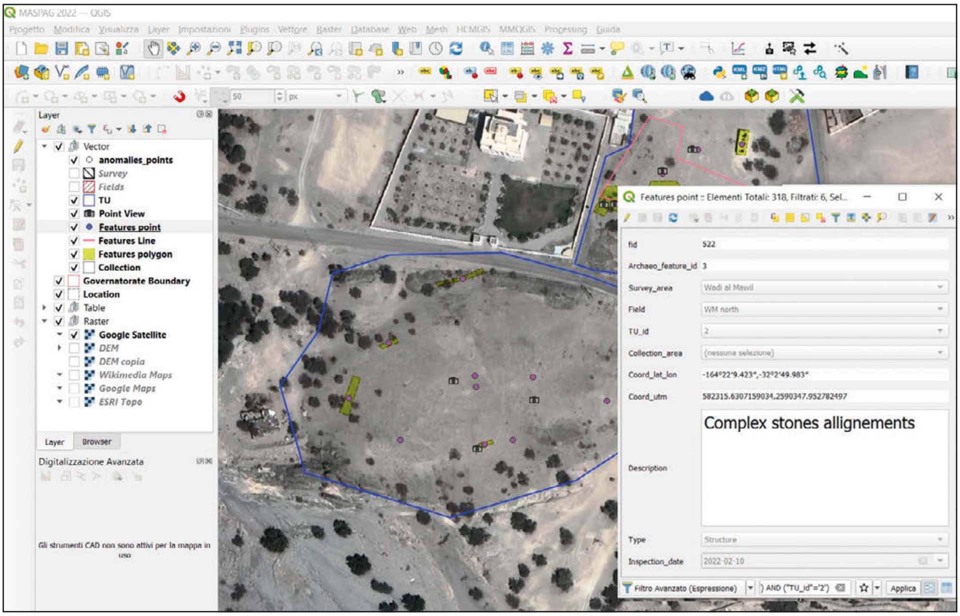


Fig. 2 – Screenshot of the QGIS project, on the left the vector layers represent the decomposition of the archaeological information.

Fig. 3 – QField in action, on site digital data acquisition directly feeding the database with points as well as pictures.

lines and polygon layers). The TU table is organised in attributes that allow its geographical description and positioning in the larger ecotope, together with the human activities observed in the field and the archaeological activities carried out. Digitised as a polygon, the TU layer becomes the container for the archaeological features identified in it (Fig. 2). The archaeological features themselves are described by an open list of categories (e.g. structure, shred concentration, stone alignments, etc.) in order to account for the very high variability expected in the archaeological landscape.

The intention to separate description from interpretation has justified this choice, reinforced above all by the high volume of photographic documentation via a dedicated point-view layer. With this structure organised in a QGIS project, we were ready to start the survey and document the landscape. QField plugin was used to enter data directly in the field (Fig. 3). This open source software synchronises a QGIS desktop project to an Android mobile device, used to draw geo-referenced archaeological features on the spot. With the application of this workflow, 25 TUs distributed along 5 Field Areas and a total of 313 archaeological features were documented during the month of fieldwork (Fig. 4).

The most prominent documented features are the about 249 funerary monuments. These last are concentrated in two main areas: Khatum West has 89 graves spread across 5 topographical units, from the rocky jebels (KTW.TU.9) to their foothills (KTW.TU.6), and to low natural rocky plateaus that are 3-4 m above ground level (KTW.TU.2 and KTW.TU.3). In contrast, the Wadi al Ma'awil South area has 152 tombs arranged more coherently in a single long series of interconnected low ridges and small plateaus that span about 3.5 kilometres in a SW direction (WMS.TU.1).

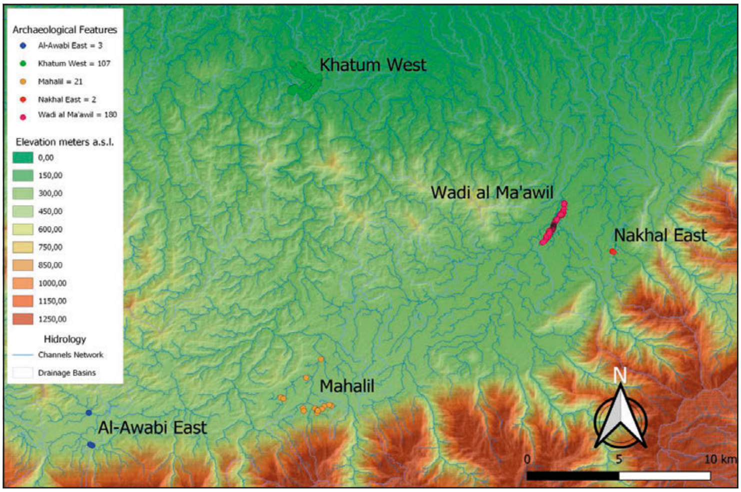


Fig. 4 – Final map showing the archaeological features documented in the landscape.

Besides the 249 tombs, there are 37 other features linked to settlement contexts (such as stone alignments, pottery clusters, lithic, etc.), 10 individual features (collected diagnostic elements such as metal slags, stone tools, and diagnostic pottery), and 17 anomalous features (such as regular soil discoloration or vegetation growth completely separate from the surrounding environment). In addition, several trigonometric points were surveyed to document and study the relationship between the archaeological landscape and modern activity, enabling us to reconstruct the recent history of the landscape's human impact.

Through this data acquisition process of the archaeological landscape, we were able to make a preliminary projection of the archaeological risk and potential of each documented Topographical Unit (TU), and thus create an Atlas of the surveyed area. Each entry of the Atlas retrieves and lays out the information related to the TUs, from its coordinates and administrative positioning to the archaeological features with their proposed chronology, up to the modalities of land exploitation today and the evaluation of the archaeological impact, the latter assessed on the based on the relationship between archaeological evidence and modern anthropic activities observed on site.

The production of the Atlas allowed us to provide the specific cartographic documentation directly during fieldwork, and our close collaboration with the Ministry of Heritage and Tourism of the Sultanate of Oman allowed us to communicate with the department of housing in order to raise awareness on the implications and importance of an archaeological assessment.

## 4. Future perspective

As highlighted above, both the training in the use of geo databases and the new QGIS documentation tool for MASPAG's survey were successful. Thus, we structured the advancement of the partnership, bringing us closer to the final goal envisioned since the beginning, i.e. the full integration of pyArchInit into MASPAG's documentation system. The promising start to this second phase was the renewal of the Research Initiation Projects (Progetti per Avvio alla Ricerca - Tipo 1), which will make it possible to develop and expand the skills and experience gained and to concretely start thinking about the scientific ramifications and possibilities that such a system can offer.

Combined with the future launch of an *ex-novo* stratigraphic investigation of selected archaeological sites, settlements and seasonal occupations while continuing field, aerial and satellite surveys activities in parallel, the preconditions are in place to enhancing pyArchInit plugin to integrate in one innovative platform the documentation of both stratigraphic excavation and archaeological landscape. The primary objective of this phase of the work is therefore to develop the integration of the structure created for the survey into the pyArchInit platform, which will enable digital management of all scientific documentation produced, from the landscape to the stratigraphic unit.

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## ABSTRACT

During the fieldwork season in November 2021-March 2022, the 'Missione Archeologica della Sapienza nella Penisola Arabica e nel Golfo' (MASPAG), as part of the research activities supported and financed by the Great Excavations of Sapienza since 2019 and MAECI since 2022, planned and launched a new landscape archaeological project in the Sultanate of Oman. The first survey was carried out in an area of the Al Batinah South Governorate unknown to archaeology, combining remote-sensing and ground verification activities. This operation also saw the first result of the collaboration between the MASPAG research group and adArte srl, developer of pyArchInit open source plugin for QGIS. The first season of the survey not only made it possible to estimate the archaeological potential of the study area, but also served as a workshop, opening a dialogue between universities and private companies, to discuss open source solutions in archaeology.

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# VIRTUAL RTI APPLICATION ON 3D MODEL FOR DOCUMENTATION OF ANCIENT GRAFFITI: PROPOSAL OF A METHODOLOGY FOR COMPLEX ARCHAEOLOGICAL SITES

## 1. Introduction

The following work was made possible by the collaboration between the Department Asia, Africa e Mediterraneo (DAAM) of the University of Naples L'Orientale and the inter-university Consortium CINECA, represented by the authors[1]. The project is about the creation of a virtual dome for RTI acquisition and has two main aims: to make possible simple RTI acquisitions in difficult environmental contexts, and to reuse for new research high-resolution three-dimensional surveys acquired for other purposes. As part of a major international project, high-resolution 3D models of the Catacombs of San Gennaro in Naples are available (https://skfb.ly/ozSsA). Among these, the present contribution analyses a frescoed niche characterised by innumerable engravings on the entire surface of the *arcosolium*. The research highlights how the combination of two different open source applications, one made for cultural heritage (RTI Builder), the other one for graphic modelling (Blender), is a valid support for archaeological analysis allowing the reuse of previous 3D data for graffiti identification. It also highlighted how the result of the V-RTI strictly depends on the resolution of the 3D model used. Finally, we underline what are the potentiality and the limits of these applications, to improve methods and practical application in a complex site such as the Catacombs of San Gennaro.

## 2. RTI methodology

Reflectance Transformation Imaging (RTI), as defined by the non-profit organisation "Cultural Heritage Imaging", which is behind the development of the RTI Builder and Viewer software and of the related methodology, is «a computational photographic method that captures a subject's surface shape and colour and enables the interactive re-lighting of the subject from any direction» in a viewer, revealing details not visible with the naked eye» (CHI 2014). RTI images, in addition to RGB colour information, record surface normals for each pixel; each value, corresponding to a point on the

[1] A.B. and E.M. conceived of the presented research and verified the analytical methods. D.D.L. developed the Virtual Dome and performed the computations. E.M. performed research activities for the state of the art and methodology. A.B. supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

object, stores information on the angle of reflectance of light coming from any direction at that point.

The RTI methodology is a reliable and widely used tool for archaeological research, in particular for the analysis of a wide range of artefacts, such as for the interpretation of graffiti and engravings and for the recording of the maintenance phases of objects, paintings or frescoes. It also enables the documentation of particular data that are difficult to visualise with the naked eye and facilitates the recognition of traces and marks on the surface of objects. One of the most widely used acquisition methodology in archaeology is the so-called Highlight Based RTI (H-RTI). It is characterised by its simplicity of use as it only requires easily transportable and low-cost equipment like a camera, a tripod and an external light source.

The H-RTI uses one or two reflective targets (usually a dark-coloured sphere) in each frame at the same position within the image frame to calculate the position of the light directly from the reflection on the sphere (Earl *et al.* 2010; Duffy 2013). It is important for the subject to be illuminated in the round by several light positions with illumination angles between 15° and 65°. For an appropriate acquisition, the camera should maintain a fixed framing while the light source will be moved in each precise angle. By applying this technique in our case study, we unfortunately run into the problem of accidental vibrations transmitted to the camera, which have a significant effect on the framing and compromised the sharpness of the RTI images.

The arrangement of light sources also has an impact on the quality of the acquired RTI data. Ideally, the positions of the lights should be evenly spaced and it is recommended to keel the source of the light at a constant distance from the surface of the subject, i.e., of two to four times the diagonal of the area to be recorded. Through the use of a RTI dome, in which each position of the light is provided by a different illumination source, it is possible to have acquisitions of great detail and precision. The so-called light-dome is equipped with a top hole for housing the camera and LEDs that allow the object to be illuminated from different points equidistant and synchronised with the camera shot. This methodology (D-RTI) is especially suitable for the acquisition of small objects and is, therefore, generally used in laboratories.

One of the main problems, both with the H-RTI methodology and also with the light-dome, lies in the size of the objects to be acquired. Images of larger objects must be acquired in smaller subsections, which increases the difficulty and duration of the process. Furthermore, an optimal H-RTI application requires full control of the recording environment and often the surveying "objects" are located in places that are difficult to reach or where it is extremely complex to plan an adequate RTI acquisition.

Fig. 1 – Elaboration process overview of the 3D point cloud of the Catacombs carried out in the framework of the acquisition project in 2019.

## 3. Case study

The evocative scenery of the Catacombs of San Gennaro was the location of an international research project focused on the 3D survey of the site, started in September 2019. The activities were funded by the private non-profit organisation GDH (Global Digital Heritage, USA), assisted by the Zamani Project (South Africa) and CISA (Centro Interdipartimentale di Servizi di Archeologia, of the University of Naples L'Orientale). In parallel with the ambitious digital survey activities of the entire hypogeum network, several H-RTI acquisitions were carried out in order to test the methodology for the documentation and analysis of graffiti and engravings (Fig. 1). The huge site of the Catacombs is developed on two non-overlapping levels of underground passages and tunnels and originates from a burial core dating back to the 2nd century CE, which was expanded during the 5th century thanks to the transfer of the remains of San Gennaro. The Catacombs became a place of pilgrimage and a favourite burial site for the population until the Saint's remains were removed in 831. From then on, the site was abandoned until the 18th century, when Naples became one of the destinations of the Grand Tour.

The multi-secular life of the site is perfectly verifiable and "readable" through countless engraved, graffitied, written and painted texts on numerous walls of the Catacombs, both above the decorations of the niches and *arcosolia*, and on portions of bare walls (Bosco, Minucci 2020). These almost completely unpublished "signatures" cover a vast chronological span and represent an interesting tangible mark of the continuous passage of people

Fig. 2 – The niche with the *arcosolium* where the H-RTI acquisition test was performed.

from all over the world. Often, names, signs and dates are superimposed and distributed in such a chaotic manner that their identification and consequent reading are complex or impossible at all.

This context is still very impressive for visitors and represents a real challenge for the researchers because of several aspects. The main obstacle to their survey is the poor lighting, also made worse by the lack of sufficient electrical connections to bring in external light sources. Secondly, the small but highly articulated spaces complicate the acquisition process by requiring more operators and more equipment. Finally, the instability of the ground surfaces on which to fix the equipment often causes blur effects in the photos. Indeed, the tombs, excavated at floor level, greatly complicates the fixing of tripods necessary for acquisitions. Moreover, metal walkways that facilitate the passage of tourists are also very common. Such footpaths, although they overcome obstacles on the ground, cause considerable vibrations, which are detrimental to the photographic acquisitions.

Classical H-RTI methodology acquisition was applied for test on some *arcosolium* burials particularly characterised by graffiti. Unfortunately, it was not possible to respect the ideal angles of light emission, due to the shape of the burial which has a deep arc, thus creating an obstacle to the illumination of the back wall, and also for the narrow spaces, which several times caused camera vibrations and restricted the operators' movements (Fig. 2). The final results were therefore not satisfactory, due to less accuracy and blur in some part/position of the object.

## 4. The Virtual RTI

The Catacombs project had, however, produced high-resolution three-dimensional surveys of the entire burial complex, combining photogrammetry and scanning acquisitions. Thanks to CINECA's work, it was possible to build a virtual dome in the open source software Blender. The idea is to operate Virtual Reflectance Transformation Imaging (hereinafter referred to as V-RTI), i.e., a hybrid method that combines 3D, virtual manipulation and 2D+ technologies in a workflow, partially carried out *in situ*, that is quick and intuitive (one only needs to be familiar with 3D modelling software) and suitable for the documentation of a wide range of archaeological monuments. The dome was recreated with characteristics reproducing as faithful as possible the real dome, so that the two environments could be comparable, but at the same time it was built to overcome the limitations of the "real" tool. Three-dimensional models generated with SfM, or other technology, are illuminated and then photographed in a virtual environment before being processed in the RTI Builder software. The first step was to

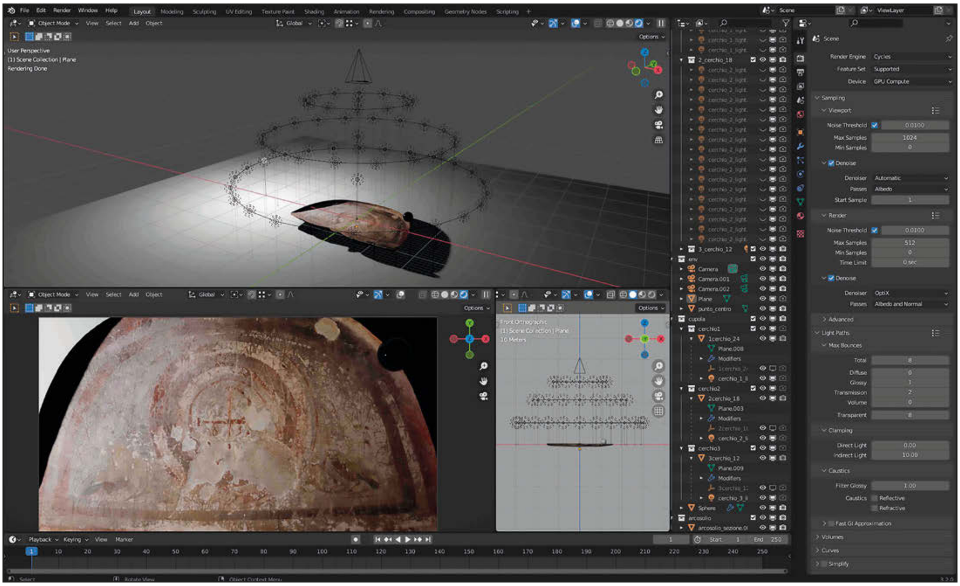

Fig. 3 – Screenshot of the 3D model with the Virtual Dome in Blender (minucci-bosco-de_luca 2022).

import the PLY file of the model into Blender. In the virtual environment the structure of the dome has been created, with three concentric levels of lights equidistant from each other.

The lights are omni-directional point type and have a power of 200W each, with a diameter of 0.03 metres. They were created as instanced copies to provide an easy way of future editing of their parameters. In the largest diameter level 24 lights were inserted, in the intermediate level 18 and the level with the highest angle of inclination had 12 lights. The target object was obtained by creating and positioning a primitive UV Sphere object, with a high level of geometry subdivisions in order to be as smooth as possible and also with smooth-shaded normals. The shader of this sphere was obtained with a glossy BSDF shader with a pure black diffuse colour and a level of roughness of 0.08, in a scale from 0 to 1 (Fig. 3).

The 3D camera was positioned at the centre of the dome, above the highest level of lights, with a focal length of 50 mm and generic 36×24 mm camera sensor, to mimic a real DLSR camera. The render engine used in this setup is "Cycles", integrated in Blender, that allows to set every light bounce to 0 to avoid colour glare and optimise shadows. The target-sphere shadows were also disabled via the Cycles visibility options of the sphere object. By running the *ad hoc* Python script, to simulate the RTI acquisition phase, the system turns off every light and then turns on one at a time, calculates and stores the captured frame, turns everything off again and repeats the procedure for all the other lights. The dome was scalable according to the model dimension and it was possible to "clean" the 3D model to remove obstacles (such as the arch) to optimise the correct illumination of the object under analysis (in our case the *arcosolium*). The activation of the virtual capture process on the wall of the *arcosolium* produced images at a resolution of 3840×2160 pixels, exported in JPEG format with a low compression rate.

## 5. RTI processing

The resulting images were then processed with the open source RTI Builder software, applying the PTM (Polynomial Texture Mapping) process. The choice of this rendering is linked to the greater availability of filters that can be applied to the finished elaboration in the RTI Viewer. The comparison with the result of the process carried out *in situ* with H-RTI clearly shows the enhancement in the readability of the information, even with the application of the filters that the software provides. The improvement of the data acquisition procedure is immediately visible in the processing phase. Indeed, after the highlight detection within the images, the software carries out the processing and makes it possible to visualise all the light spots detectable

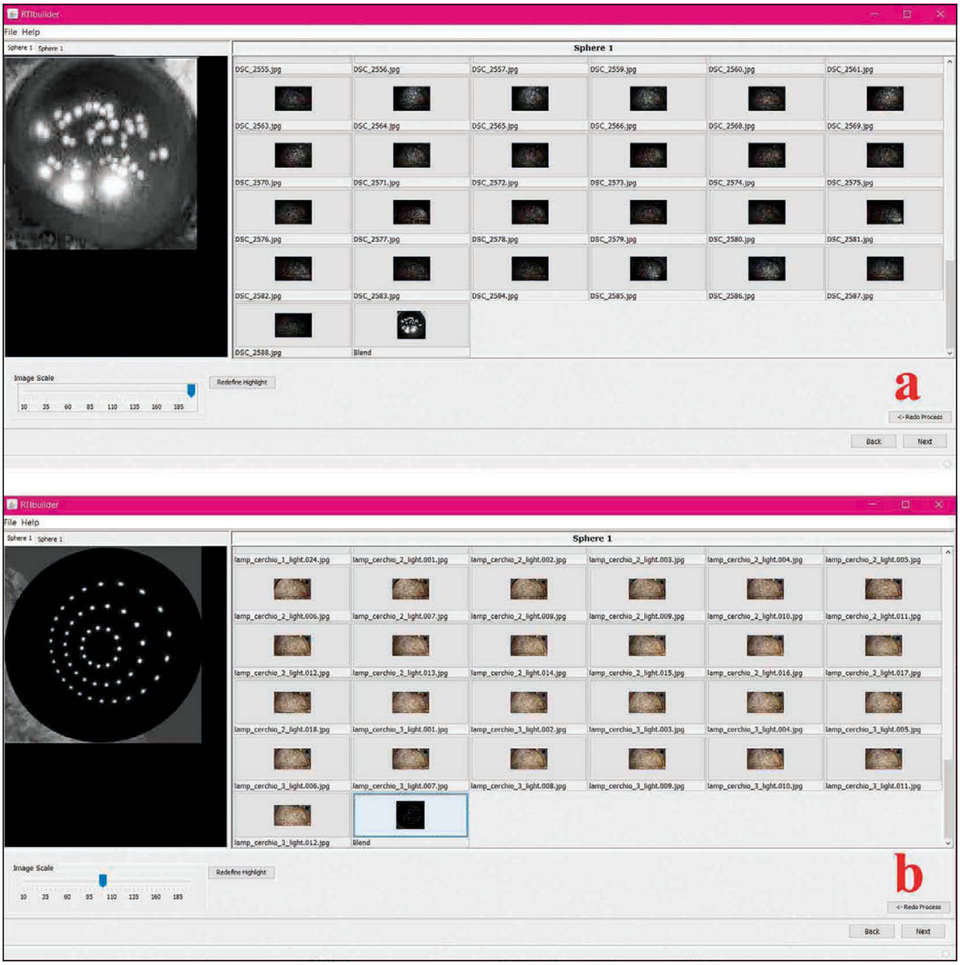


Fig. 4 – Two screenshots of the highlight detection in the RTI Builder software. a) Irregular diffusion of light in the detection of *in situ* H-RTI acquisition; b) Regular light distribution in the V-RTI process.

on the sphere. As shown in Fig. 4, the difficulties and obstacles found in the field resulted in an uneven rendering of the acquisition, clearly visible on the reflecting sphere. On the contrary, the virtual environment allowed a correct and homogeneous distribution of the light source. A marked improvement in visualisation is visible in "Default" rendering and even more so with the application of filters such as the "Specular" (Fig. 5), where the strong shadow seen in the processing from real shots gives way to a palpable emphasising of the micro-reliefs on the surface of the *arcosolium*.


Fig. 5 – Comparison between the Default and the Specular renderings in RTI Viewer on the *in situ* and Virtual elaborations (minucci-bosco-de_luca 2022).

## 6. Conclusion

In a nutshell, the H-RTI method is recommended for medium-sized and outdoor acquisitions, but it is unsuitable for complex sites due to the specific execution procedures. The use of a light dome in the D-RTI methodology allows for a controlled and stable acquisition environment, thanks to the automatic management of illumination. However, it is suitable for small objects and surfaces and is not always adapted with ease to outdoor acquisitions. The application of Virtual RTI has proven to be a valid alternative that fits into an increasingly consolidated digital survey workflow.

The advantages of the V-RTI are many: (i) since the virtual dome can be scaled and rotated to different positions, the V-RTI methodology is efficient when the object is too large for a traditional RTI acquisition or when this is geometrically complex. (ii) The virtual environment also allows to solve the problems deriving from the shape of the object, which can hinder a correct illumination, and those of the self-occlusion caused by the shadows of the illuminated target sphere that can be found on the surface of the object, thanks to the possibility of "cutting" the 3D replica as required. Furthermore (iii) the V-RTI is very useful in remote contexts, in sites which are difficult to access or where planning an adequate Highlight Based acquisition would be tricky or too time-consuming at a logistical level and where therefore too many acquisitions are not recommended *in situ* (this is the case of the Catacombs of San Gennaro, a vast hypogeum maze characterised by special soft lighting and visited every day by large tourist flows). (iv) The V-RTI methodology also provides greater objectivity than the H-RTI methodology, since it is not necessary to select only one view of the object while in the field. (v) The opportunity to choose different shots in the virtual environment for each detail to be analysed allows for a more reflexive approach to investigations, especially in contexts where it is not possible to repeat acquisitions. Finally (vi) the surface of the objects can be resurveyed and illuminated from different positions after the acquisition of the models, allowing an almost infinite re-investigation in the light of ever new research questions.

Obviously, V-RTI is strongly affected by the resolution of the 3D model being used as a source of information. However, 3D surveying methodologies are, to date, extremely advanced and versatile, guaranteeing excellent data even in difficult environments. The possibility of using polygonal 3D information from any 3D acquisition methodology (photogrammetric, time-of-flight or phase-time laser scanner or even structured light) makes the virtual dome compatible with the most different research pipelines available. The case study made it possible to outline an overview of the methodologies under investigation and to lay the bases for the creation of a comprehensive research protocol for the use of the V-RTI technique. For this reason, the authors are working on making this digital tool available to other research groups, in order to expand the application cases and share possibilities for improvement.

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ABSTRACT

In the field of Cultural Heritage, the technological advances of recent years have enriched and optimised the possibility of documenting and studying ancient graffiti with a wide range of low-cost and non-invasive methodologies. The most popular are digital photogrammetry SfM (Structure from Motion) and RTI (Reflectance Transformation Imaging) methodologies. The RTI is a powerful tool that, through the use of open source software, enables the documentation of data that are difficult to visualise, facilitating the recognition of traces and marks on the surface of objects. On the other hand, the SfM 3D models are increasingly replacing documentation with traditional photographs. This 'almost excessive' production of three-dimensional models is not often accompanied by an adequate exploitation of all their potential uses. This research aims to investigate the possibility of using a high-resolution 3D model for the implementation of virtual RTI processing, a hybrid method that combines 3D, virtual manipulation and 2D technologies in a fast and intuitive workflow suitable for the documentation of a wide range of archaeological monuments. The process sees the 3D model from the SfM survey being illuminated and photographed in a virtual dome in the open source Blender environment; therefore, the images generated are processed with RTI Builder software.

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# OPERATIVE TOOLS FOR BIM IN ARCHAEOLOGY: LIBRARIES OF ARCHAEOLOGICAL PARAMETRIC IFC OBJECTS

The creation of 3D models for Cultural Heritage has now become a common practice for the study and enhancement of works and contexts. Today, the progress of technologies applied to the survey and management of 3D data allows us to obtain high-resolution virtual replicas, in a short time and at a low cost. Within our contribution, we present the application of a BIM methodology to the management of archaeological contexts. BIM represents today one of the innovative technologies that allows to manage not only 3D models of existing objects, but also and above all, to connect a large amount of information of different nature to those models. All this data allow us to develop research, analysis and new surveys, because they are part of a real, complete data platform.

BIM was born as a method of designing infrastructures. Today, largely widespread in professional realities, it has become a common practice for engineers and architects. With BIM design, which takes place through a specific software, it is possible to create a 3D model of the building to be built, by using for each part of it, the so-called parametric objects. Parametric objects are three-dimensional models of structural, architectural and engineered system elements that are part of the existing or the planned building. They are defined as parametric because they have a large amount of information inside. This information concerns their geometrical shape, their morphology and the material and technique with which they were built; all the data inserted inside the parametric objects can be queried and form the basis for subsequent scientific analysis. Through a BIM, it is possible to create a real management system for the construction of an asset, a public work or a building, because it provides a platform for monitoring all its phases of life and a tool to control its management and maintenance activities (Fig. 1).

## 1. BIM and Cultural Heritage

Over the last few years, especially in Italy, BIM applications have shifted to Cultural Heritage and have been adapted to historic buildings. This created the basis to develop analytic "Scan to BIM" processes, stressing on the need to obtain high-resolution and geometrically reliable surveys for historic buildings. HBIM, Heritage or Historic BIM, represents a consolidated reality within the scientific debate that focused, above all, on the detailed modelling of particularly complex elements part of the historical architecture, trying to create BIM models as close as possible to the existing reality (Murphy *et al.* 2013, 89-102).

In the last ten years, BIM made its way through the international archaeological debate, raising curiosity, questions and new challenges. The greatest

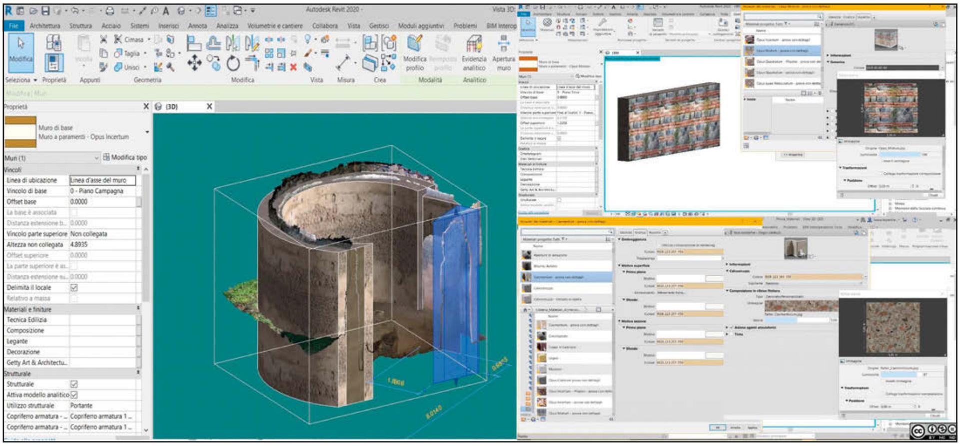

Fig. 1 – Parametric modelling of an architectural element complete with texture. On the right, an image of the Properties Sheet with the specification of construction information.

potentiality of the use of BIM methodology in the archaeological field lies in the chance to obtain a three-dimensional reality-based model of the asset. Furthermore, the asset itself gets enriched with a large amount of information, becoming a real database. The data storage system within a BIM model provides a unified database for the design of maintenance and enhancement activities and to plan subsequent analysis. Moreover, it allows the creation of virtual reconstructions on the basis of the real geometric data of the archaeological evidence. Several teams have used BIM to generate three-dimensional models of archaeological sites. Examples are provided by the reconstructions of the Temple of Uni in Marzabotto and of the Solar Temple of Niuserra in Egypt. In the first case, the rules of Vitruvius' *De Architectura* have been used as a reference to recreate in BIM the temple's elevation (Garagnani *et al.* 2016, 251-270; Gaucci-Garagnani 2020, 181-188); in the second, measurements of the building material scattered in the site were used to propose the reconstruction (Bosco *et al.* 2018, 377-388).

For BIM or HBIM the major difficulty is recreating the variety of evidence present within an archaeological site. A BIM model indeed is based on the interaction of individual parametric objects: they create the model itself and allow the representation of the reality of the archaeological context. The project we present here proposes the creation of parametric BIM objects that can better represent the archaeological reality in all its complexity (Carpentiero 2018, 1-21; 2020, 69-86).

For object modelling, Autodesk Revit software has been chosen. Revit is organised in order to have a hierarchical subdivision of the parametric objects. This routine is closer, than it might seem, to the archaeological classifying process, because the ancient evidence is subdivided likewise by archeologists: in typology and building techniques. This subdivision is organised by Discipline and analytical Categories. For Discipline, we can identify three main topics: architecture, structure and systems. As to the analytical Categories, we have three: Family, Type and Instance. Each parametric object is identified by the categories it belongs to; for each Family of objects, numerous variations of Type are created, based on the variations of the object parameters. For example, in the Revit classification process, a Wall object would belong to the "Walls Family". Then, regarding the Type, there could be many different types of this family, based on different parameters like the geometrical shape changes and the construction technique.

## 2. A semantic library's model for Roman domestic architecture

In order to implement on a scientific basis the BIM methodology and make easier and faster the modelling of archaeological structures in a software created for modern architecture, a model of semantic library has been created. This model is very useful because the BIM archaeological objects it contains can be reproduced, and possibly modified, for other projects. The site of Pompeii has been chosen to be the reference context for the creation of this library. Considering its extraordinary state of conservation and the wide variety of architectural types it offers, Pompeii constitutes an essential point of reference for research concerning Roman architecture of the Republican and early-Imperial age. Later, in a second phase of research, the variety of types identified at Pompeii will be developed further and completed by using data coming from another site destroyed by the Vesuvian eruption in 79 CE, Herculaneum, where different destructive dynamics permitted the preservation of evidence that is no more recordable in Pompeii.

The Vesuvian context is therefore a valid field of experimentation to evaluate how to transform a BIM information system into a tool that can effectively support archaeological research, especially in the phases of data organisation and interpretation. These reasons led to the development of a research project whose aim is to adapt potentialities of BIM to the archaeological context, through the analysis of evidence discovered in Vesuvian sites. This goal will be achieved in two ways: on one hand, by perfecting the modelling phases through a case-study chosen in the domestic architecture of Pompeii (houses I 16, 5, 6 and 7[1]); on the other hand, by creating a semantic library model, exportable and including a range of parametric objects so wide and varied that it can correspond to the entire set of elements that would be part of a Roman building's BIM model. Here, the creation of the semantic library will be discussed.

[1] These houses are studied in the scope of a research program dedicated to the *atrium testudinatum* house of Pompeii "Modes d'habiter à Pompéi à l'époque républicaine", supported by Centre Jean Bérard, University Paris Nanterre and University of Naples L'Orientale: D'Auria, Ballet 2020.

| Discipline | Family | Function | Morphology | Building technique | Materials |
|---|---|---|---|---|---|
| Structural | Wall | Outer wall – Front wall<br>Outer wall – side wall<br>Dividing wall<br>Retaining wall<br>Cellar wall<br>Enclosure wall<br>Partition wall | With parallel sides<br>With non-parallel sides<br>Buttressed<br>With niches<br>With half-columns<br>Mixed lines | *Opus quadratum*<br>*Opus africanum*<br>Irregular *opus incertum*<br>*Opus incertum*<br>*Opus incertum* with rows of bricks<br>*Opus testaceum*<br>*Opus reticulatum*<br>*Opus quasi reticulatum*<br>*Opus mixtum*<br>Panelled *opus mixtum*<br>*Opus vittatum*<br>*Opus vittatum mixtum*<br>*Opus craticium*<br>*Opus formaceum*<br>*Opus latericium* | Sarno limestone<br>Lava<br>Nocera grey tuff<br>Napolitan yellow tuff<br>Foam lava<br>*Pappamonte*<br>Baked bricks<br>Cut tiles<br>Mud bricks<br>Clay<br>Wood |

Tab. 1 – Creation of the archaeological BIM object: wall element's declension, based on the analytical Categories of Revit software.

At the origin of the creation of the semantic library model, there is a repertoire of architectonic and structural elements, as well as of hydraulic and thermal systems elements, of which a Pompeian house could be made of. This repertoire has been developed by both a bibliographic[2] and a field survey, the aim being to gather all the possible variants of the elements. To identify these variants, the entire set of their features has been taken into account, as the variation of one of them can be regarded as a discriminating factor for the type identification. Therefore, for each parametric family of objects, the architectonic function, the morphology and the composition of each element have been analysed. For example, in the case of the "wall family", that makes part of structural objects, the different functions of the element inside the building have, at first, been identified (Tab. 1). A wall, indeed, can be an outer wall, a dividing wall, a retaining wall or a cellar wall and have therefore a load-bearing function; or it can be a partition or an enclosure wall and have no load-bearing function. Then, its shape in plan has been considered and finally, its composition, identifying materials and building techniques employed for its construction. These latter have been indicated by using the traditional nomenclature of pompeianist studies. However, to get an easier identification of building techniques and of library's types, it has been considered worthwhile to guarantee an unambiguous

[2] Useful are the analysis and categorization of ancient buildings' architectural elements, based on the different steps of the construction process, provided by Ginouvès, Martin 1985; Giuliani 1990; Ginouvès 1992. More recently, researches of ACoR program resorted to this sort of approach, see Camporeale *et al.* forthcoming.

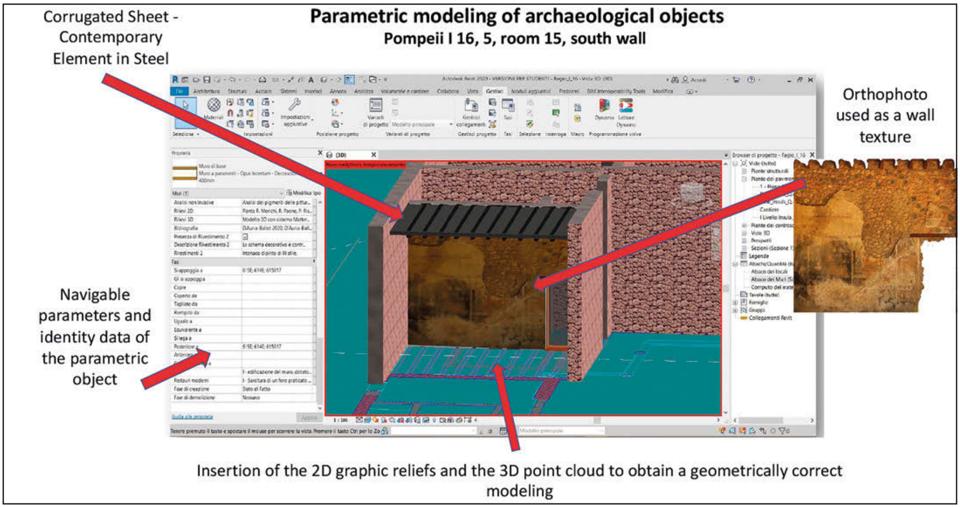


Fig. 2 – Insertion of information elements related to parametric modelling.

identification of data, by linking them to standard systems like Art and Architecture Thesaurus (https://www.getty.edu/research/tools/vocabularies/aat/) or Thésaurus PACTOLS (https://pactols.frantiq.fr/).

Based on the Pompeian archaeological evidence, in addition to the library of archaeological parametric objects, we created a library of building techniques specific to the Pompeian context, to be applied to individual objects (Fig. 2). Each element modelled in BIM is accompanied by its own construction technique, which is made browsable in the model by reading the internal stratigraphy of the elements. Each building technique is organised in Material tabs that group together the description of the technique, the pattern used for the texturing of the elements and the graphic appearance (line and fill style) that the material assumes within the *.dwg tables that can be extracted from the model. In order to obtain an excellent graphic rendering of the parametric objects modelled in BIM, orthophotos, obtained from photogrammetric surveys, were used as a texture for the external facings of the walls.

Correlation of data to the semantic library's objects is possible thanks to abacus. These are tabular structures that, in the scope of this project, have been enriched by a series of specific items, transforming them into a useful tool for archaeological analysis. This operation allows the adaptation of BIM to the archaeologist's needs and its transformation in an information system suitable to the management of data coming from archaeological investigations. In the case of a wall, for example, it is possible to fill the abacus with records concerning different topics (Fig. 3). In our work the following elements

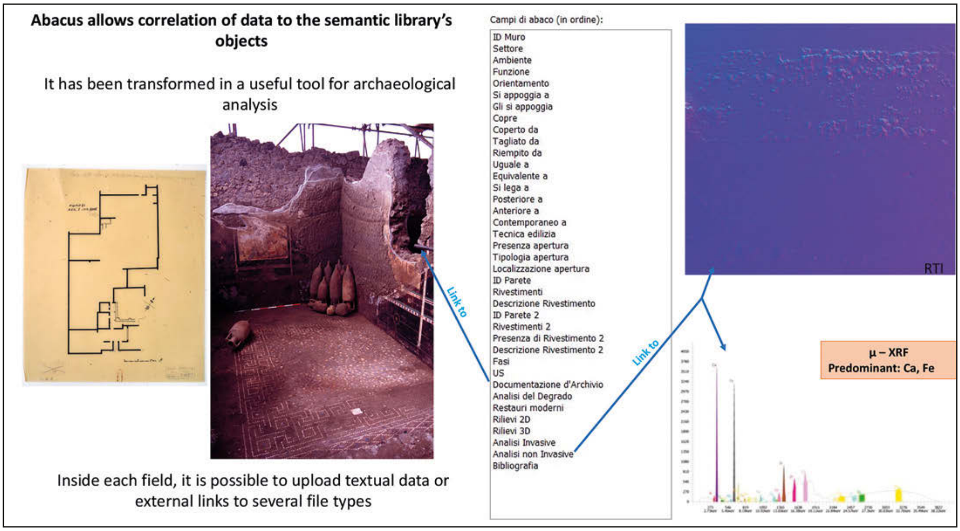


Fig. 3 – *Abacus* with entries dedicated to the specific archaeological evidence. All the items entered in the model can be queried and allow the definition of future analyses on the building (courtesy of Ministero della Cultura - Parco Archeologico di Pompei; copy or reprint is prohibited).

have been taken into account: the position of the wall inside the building, its function, the stratigraphic relationships with other elements, its constituent features – like the building technique employed – or its morphological features – like its shape or the presence of openings – and the presence of a coating and its features. It is also possible to include data about the element's building history, its discovery (such as archive data or bibliography), the investigations it had undergone (as instance, invasive and non-invasive analysis) or about the graphic (2D and 3D surveys) and photographic documents, and the deterioration monitoring (building survey, modern restorations).

Inside each filled, it is possible to input textual data or external links to several file types, including the ones for images and 3D reconstructions. Data filed in the abacus are then summarised inside a "property sheet". This property sheet supports any parametric object and is automatically displayed each time that the object is selected. In this way, the user may have an immediate overview of all data linked to the object, allowing therefore an easier management and query within the system.

## 3. An IFC interchange format

Despite the fact that in the present case a proprietary software has been used, the archaeological parametric objects can be exported, without alterations

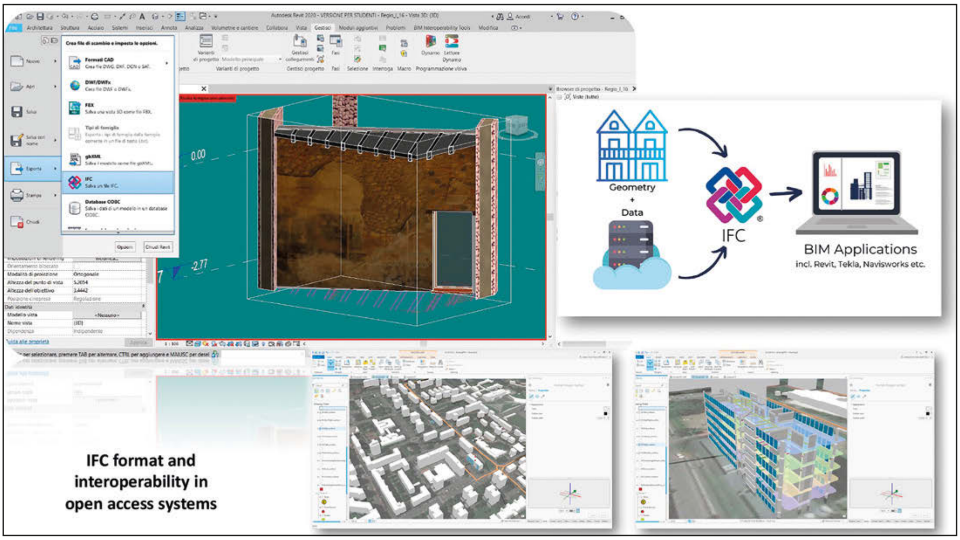


Fig. 4 – Export of archaeological BIM objects in the IFC interchange format.

or variations, in the IFC interchange format (Fig. 4). The IFC interchange format allows the BIM object to keep all the geometric and graphic characteristics and all the specific information, such as all the values in the property sheet, identified as the real attributes of the parametric object. The exported *.ifc files can be imported within all the software working in the BIM environment and are available on all modern Operating Systems. The export of archaeological objects in IFC format allows to bring BIM modelling closer to the FOSS world.

The proposed work, even though in its initial phase, aims to provide operational tools, of wide access and ready-to-use, for the creation of BIM models of archaeological contexts. The BIM objects have been modelled and defined on a scientific basis and are able to represent a wide range of evidence within the domestic architecture of Pompeii. A library of parametric archaeological objects modelled using the Autodesk Revit BIM environment software was created and exported in IFC format. The archaeological BIM objects have been enriched with graphic and constructive information that allow them to be used in all the BIM modelling of archaeological Roman domestic building structures. The IFC format enables to overcome the limitations of using non-FOSS software and create interoperable tools to use BIM as a management model for archaeological contexts.

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## ABSTRACT

Building Information Modeling is the most consolidated work method for engineering design of buildings and infrastructural works. It allows to create a comprehensive database starting from a 3D model of a building. Its use in archaeology permits to test and transform a working method, born for engineering design, in an operational support for archaeologists during and after the field phase. Our contribution focuses on the application of BIM to archaeological evidence. It presents the initial stages of a research project, whose aim is the definition of operational solutions for the creation of BIM models. To implement, on a scientific basis, the BIM methodology and make the modelling of archaeological structures easier, a model of semantic library, based on Pompeian archaeological evidence, has been created. The BIM contains archeological objects that can be reproduced and possibly modified for other projects. They represent a support to share on a large scale the representation in BIM. All archaeological library's objects can be exported in the IFC format. This format can be opened and edited by all BIM software and worked on all OS; the export of archaeological objects in IFC format leads BIM closer to the FOSS world.

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# ARCHEOLOGY AND CONSERVATION. DIGITAL TOOLS AS DIGITAL BRIDGES BETWEEN DISCIPLINES: THE RISK MAP OF THE *IN SITU* MOSAIC AND MARBLE FLOOR SURFACES OF THE PARCO ARCHEOLOGICO DEL COLOSSEO

## 1. Arguments for the project

Since 2018, the Parco Archeologico del Colosseo has been engaged in the project "Risk Map of the *in situ* mosaic and marble surfaces of the Parco Archeologico del Colosseo" (Lugari, Rinaldi 2020). The archaeological area of the Palatine, the *Domus Aurea* and the Roman Forum include more than 200 floor pavements. The list includes cocciopesto floors used in the service rooms, but also, and most importantly, black and white tessellated and *opus sectile* marble floors for the representative rooms. Some of these floors can be seen inside the houses and palaces on the Palatine hill (the House of the Gryphons, the House of Livia, the House of Augustus, the *Domus Transitoria*, the *Schola Praeconum* and the *Paedagogium* on the southern slopes of the Palatine), the civil buildings (*Basilica Aemilia* in the Roman Forum and *Curia Iulia*) and in places of worship (the Church of S. Maria Antiqua).

Open-air floors are particularly abundant and amongst these are the *sectilia pavimenta*, artfully constructed with a combination of coloured marbles, clearly recognizable in the gardens and rooms of the Flavian Palaces (*Domus Flavia* and *Domus Augustana*) and in the *Domus Aurea*. These are the most fragile floors because they are subject to thermal stress of high summer temperatures and winter frost and to the trampling of the 20,000 tourists who visit and literally walk through this extraordinary compendium of history and architecture every day, not always aware that they are walking inside a representative space, a corridor, a portico frequented in ancient times by ordinary Roman citizens or emperors. Most of these mosaics were catalogued and studied in the 1960s by M.L. Morricone Matini (Morricone Matini 1967; D'Alessio *et al.* 2018) and in recent years have been digitised by the University of Padua in the context of the TESS project (http://tess.beniculturali.unipd.it).

## 2. A multidisciplinary team for mosaics and sectile heritage maintenance

In order to maintain this cultural heritage *in situ* and to tell its story, the Parco Archeologico del Colosseo has been carrying out a monitoring and maintenance programme since 2018. The first results were made known

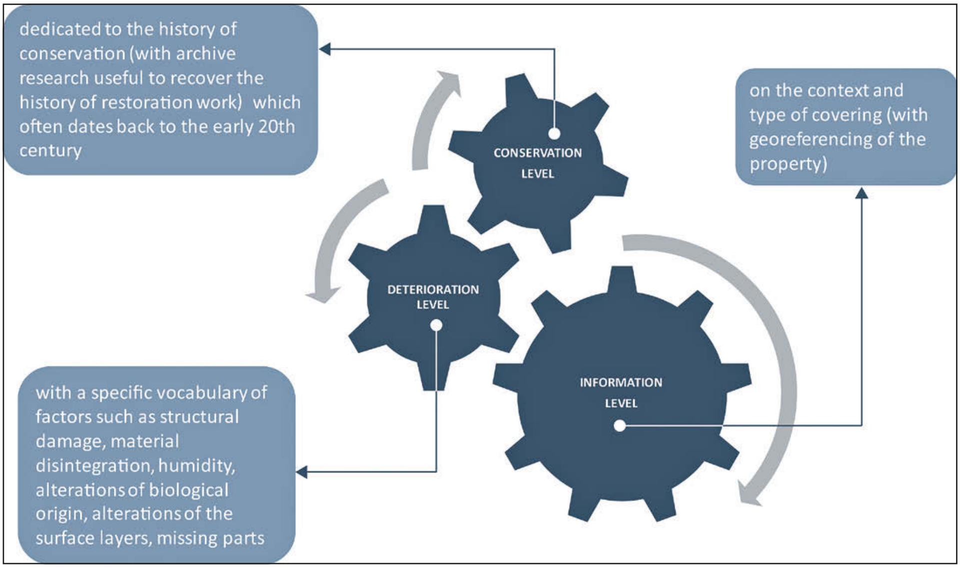


Fig. 1 – Brief description diagram of the adopted multi-level approach.

on 21th March 2019 in *Curia Iulia* at an international workshop (Rinaldi 2020). Specific and relevant monitoring and prevention measures, to counter the risk of decay or loss, have been designed for this particular category of materials. Three types of extreme events, in particular, were taken into account: 1) biological attacks by weed vegetation; 2) climate change; 3) the "social" context, i.e., the impact of tourism that undoubtedly ranks among the primary causes of "wear and tear" of pavement levels. A multidisciplinary team of archaeologists, architects, restorers and computer scientists was set up to deal with and manage this complex task in the best possible way, which first tested a multi-level sheet (Fig. 1):

1. information level on the context and type of covering (with a detailed georeferencing of the property),
2. conservation level dedicated to the history of conservation (with archive research aimed at recovering the history of restoration work – which often dates back to the early 20th century),
3. deterioration level from specific factors such as structural damage, material disintegration, humidity, alterations of biological origin, alterations of the surface layers, missing parts.

The combination of these levels provides the severity index and therefore the urgency of the intervention.

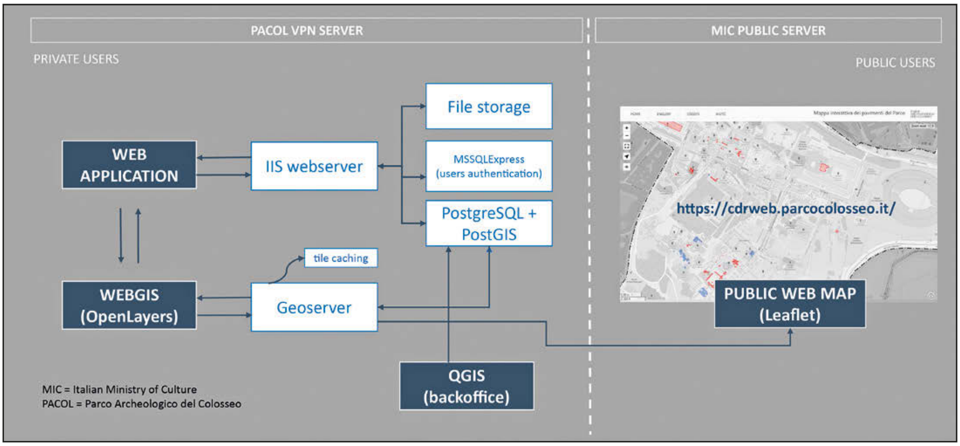


Fig. 2 – Diagram of the logical architecture behind the web platform.

Fieldwork has made it possible to move from emergency maintenance to periodic routine maintenance involving scheduled monitoring for each floor unit according to its criticality, reducing the "risk" of damage and turning it into "value". This monitoring made it possible to draw up a direct pavement intervention plan, which included a status report, followed by cleaning operations, stabilising mobile elements, restoring and preserving the perimeter edges of the preserved fragments and, where necessary, applying systems to prevent the regrowth of infesting vegetation, and periodic biocide treatments on the surfaces. Seasonal coverings with Delta® Lite sheets have been arranged for a selection of floor coverings for when temperatures reach alert levels both in summer and winter (Lugari 2017). Finally, a treatment of the *lacunae* was studied and tested, aimed at both restoring the original design with the chromatic alteration of the *breccia* placed to fill the *lacunae* and isolating them from weed roots, thus better preserving the mosaic or marble floor (Rinaldi *et al.* 2022).

## 3. From field maintenance to the "Risk Map" webGIS platform

Once this initial stress test phase was completed, which also served to identify and codify the treatment of the gaps and the aesthetic and final presentation of the floors after restoration, it was decided to proceed with data digitization and management inside a comprehensive webGIS environment (Fig. 2). Inside the webGIS platform – daily updated with running activities and new images – a historical-archaeological section for each building together with a dedicated "floor unit form" was prepared, divided into:

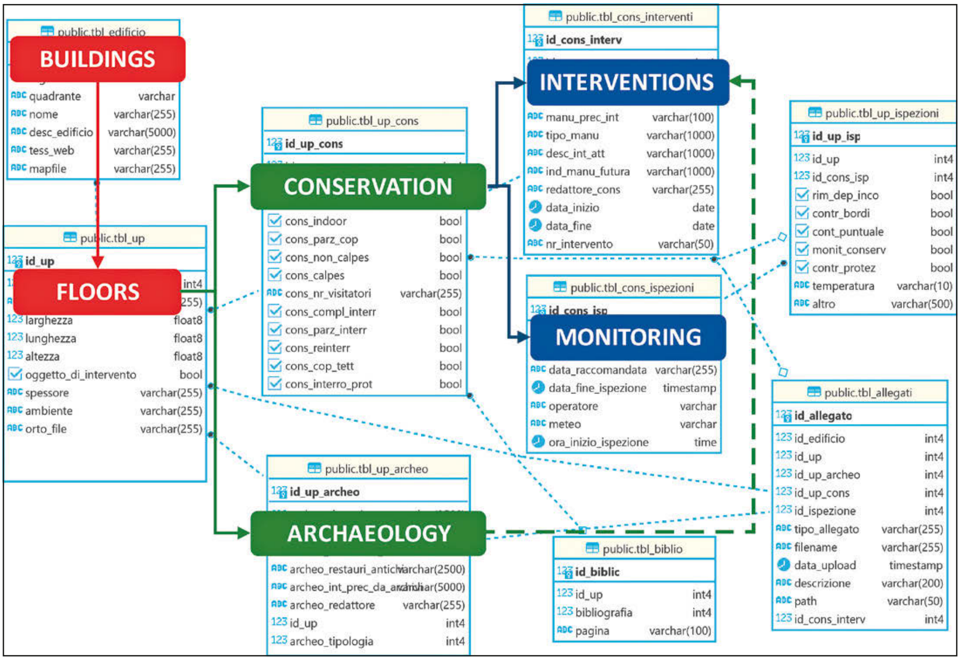


Fig. 3 – Database schema and its main entities.

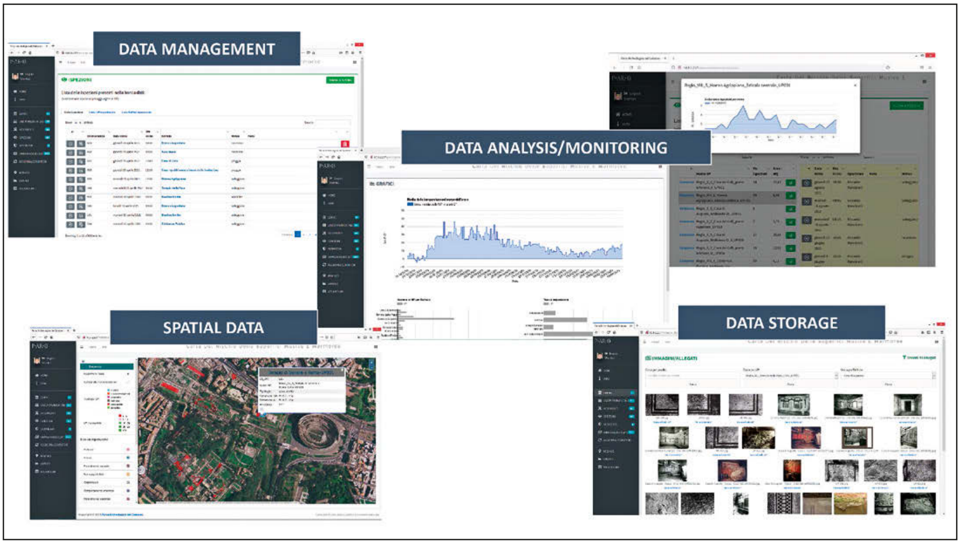


Fig. 4 – Main features and tools available inside the web application.

1. the archaeological part, including a description of the floor, the decorative type (cement floor, mosaic, paved, *opus sectile*, *opus spicatum*), dating, bibliography when available, photographic attachments, and all information gathered from archives research;
2. the conservation part, where the state of the art is described, and therefore the type of exposure to degradation, the presence or absence of covering and protection, both stable and seasonal.

The web application works as a back-office repository and management system for data manipulation and storage, whereas users on a PostgreSQL/PostGIS database record spatial and attribute data daily (Boldrighini *et al*. 2021). The interaction with the webGIS section, based on OpenLayers, is delegated to Geoserver services running on the same server. In order to manipulate spatial data, a secure connection to the geodatabase is established directly through QGIS tools. The public server, based on Apache web server, connects to Geoserver web services and is used mainly to allow public users to interact with a selection of data extracted from the main database. We can summarise the main aspects by entering the geodatabase and its relations (Fig. 3). Buildings and floor pavements are the two main entities: several tables are related to these entities in terms of archaeological information and conservation data. Daily activity concerning monitoring and interventions is stored dynamically in specific tables related to main entities.

The web application illustrates what we have observed regarding the data schema. Its main features can be summarised as follows: 1) sections for data management (inserting, updating, uploading, etc.); 2) sections dedicated to secure data storage and indexing; 3) webGIS section for spatial data interaction and visualisation; 4) a custom section for data analysis based on Google graph libraries; graphs are dynamically connected to the database and are updated automatically. The information system has been designed based on the real needs of professionals and is proving to be a valid tool for the optimization and integration of conservation and archaeological data with operational activities, with a view to medium and long-term action and programming. The improvement achieved with this kind of digital tool must be seen mainly in regard to its dynamic approach to user demands oriented data collecting, in order to connect, relate and inform conservation practices to archaeological information of the ancient floors. This kind of "connected" approach was able to trigger the correct awareness of heritage values and significance in order to create the right balance between conservation and enhancement needs (Fig. 4).

The webGIS constitutes the back office of our daily work; it is accessible to "employees" using passwords, and is aimed at sharing and enabling access of this heritage to all visitors, both *in situ* and online.

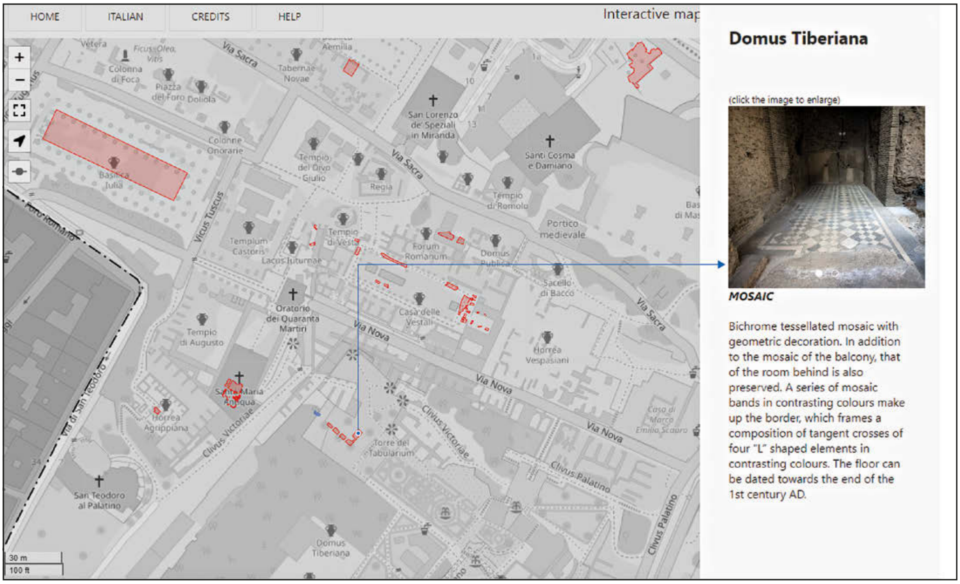


Fig. 5 – Public web map (https://cdrweb.parcocolosseo.it/).

## 4. From maintenance to educational and enhancement approaches

At the end of the first three-year phase of the project, an interactive web map was published online in May 2022 to share selected data regarding the ancient floors of the Parco with public users (Rinaldi *et al.* 2023). At this stage the web map (https://cdrweb.parcocolosseo.it) allows access to descriptive texts and image galleries of the ancient floors and there are plans to improve data sharing through API and web map services (Fig. 5). The polygons regarding the floors have been digitised on the map using the available archival graphic documentation (maps, rasters, orthophotos, detailed vector surveys where existing), and the same polygons have been made interactive, allowing immediate access to the simplified files of each floor.

By clicking on each polygon the floor's file is displayed along with a gallery of images that visually provide historical and archive data and information, as well as information on how the floor was restored and conserved and the type of floor and therefore its dating. The descriptive texts are in Italian and English and are being implemented progressively. The floors included in the ordinary visiting routes of the public of the Parco Archeologico del Colosseo were published first covering the sectors of the Roman Forum (House of the Vestal Virgins, Fountain of Giuturna, *Basilica Aemilia*, *Curia Iulia*, *Horrea Agrippiana*) and of the Palatine (*Domus Flavia*, *Paedagogium* and *Schola Praeconum*). Over time the map will also be updated with data from the so-called "super" places (Church of Santa Maria Antiqua, House of Augustus, House of Livia) or from the areas where visits are not permitted except for study and conservation reasons.

The goal is to offer an exhaustive panorama of decorated floor surfaces, to convey the value of these precious indicators of luxury (or service) in ancient residences, and to reduce the risk of indiscriminate and "misunderstood" trampling. If used appropriately the map lends itself not only as an interactive guide to deepen the knowledge of covering techniques, but also as a tool to build itineraries on a chronological or thematic basis.

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ABSTRACT

In 2018 the Parco Archeologico del Colosseo set out on a three-year basis project, the 'Risk Map of Floors Surfaces', with the aim of preserving and monitoring all the in situ floor coverings of the Roman Forum and the Palatine Hill areas (mosaics, sectile, cement floors, spicata). In order to systematically address this methodological approach a team of archaeologists, architects and restorers designed and created a comprehensive and functional information management system, the 'Risk Map of the Mosaic and Marble Surfaces', together with a web-based application with integrated webGIS tools. The platform is used daily to record historical-archaeological and archival data and it has become an essential tool in planning interventions in the field. This approach brings the Parco to move from emergency maintenance to a continuous cycle of systematic maintenance. At the end of the first three-year phase of the project, an interactive web map was published online in May 2022 to share selected data related to the ancient floors of the Parco with public users. At this stage, the web map (https://cdrweb.parcocolosseo.it/) allows to obtain descriptive texts and a gallery of images of the ancient floors; there are plans in the next future to improve data sharing through API and web map services.

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# IDAI.FIELD: DEVELOPING SOFTWARE FOR THE DOCUMENTATION OF ARCHAEOLOGICAL FIELDWORK

## 1. Introduction

The German Archaeological Institute (Deutsches Archäologisches Institut, DAI) conducts a variety of different types of field research, each with its own unique documentation requirements: excavations, surveys and architectural surveys. The resulting differences are reflected in the workflows, the recording methods and the documentation. In addition, the DAI's international work has to comply with the guidelines of the respective heritage agencies in the host countries. This results in a whole range of requirements that software for field data recording must fulfil:

– It must provide a sufficiently flexible, adaptable data model.
– At the same time, a standardised core data schema should allow for data comparison across geographical, temporal and thematic boundaries.
– Multilingual data entry must be possible.
– It must work both offline and online and allow robust methods of (delayed) data synchronisation.
– It should also be possible to publish primary research data, together with the research results, with minimal additional effort and in accordance with the requirements of the international research community and the funding providers.

An initial version of a unified field recording system for the DAI was based on the proprietary software Filemaker. This was used and modified by numerous projects at the DAI. However, systematic evaluation revealed problems in guaranteeing data quality and comparability as well as integration into existing workflows. Furthermore, the use of proprietary software and its closed data formats caused problems with upgrades that broke backward compatibility. For these reasons, the decision was made to design the new iDAI.field from scratch, relying exclusively on open source software and current web technologies. The focus of the redesign was on enabling complete documentation of archaeological fieldwork and its automatic synchronisation/integration between peers working on site. This distinguishes iDAI.field from more generic platforms, such as GIS or CAD.

The individual roles of the software were split into separate components: a desktop application for on-site data entry, a server component for synchronisation via the Internet (or a local network) and an online platform for publishing the primary data. So far, the focus has been mainly on transferring already known, analogue documentation workflows into the digital application. In the future, it should also be evaluated whether and how the possibilities of using these digital technologies can improve those workflows in order to open up new knowledge discovery processes.

## 2. Development history

Previously, the DAI used a whole range of individually developed, project-specific systems for the digital documentation of field research. Maintaining these systems was resource intensive and there was no uniform data model. Information stored in these systems could not be easily compared and was only published in the context of traditional publications. In order to overcome this, the development of a modular system was started, which should both meet the requirements of the individual projects and offer sufficient data conformity to be able to compare the collected data with one another later on.

The first version of iDAI.field was developed from summer 2006 (Schäfer 2011; Cuy *et al.* 2019) by the IT department of the DAI and the Cologne Digital Archaeology Laboratory (formerly the Research Archive for Ancient Sculpture) at the University of Cologne (Fig. 1). This version was developed in close cooperation with the Pergamon excavation of the DAI Istanbul and initially adapted to their requirements. The system was also used there for the first time. In 2008, a so-called master clone of the database was

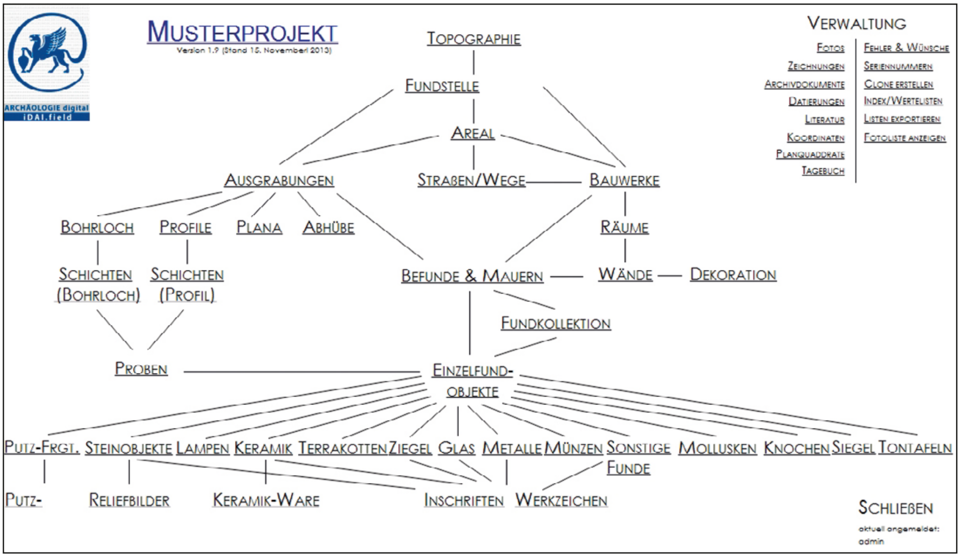


Fig. 1 – The first version of iDAI.field: 1.0. Screenshot of the welcome page with an overview of existing categories and the project management options.

created, which could be copied and thereby made available to other projects for use. In 2009, a multilingual prototype was added. FileMaker was chosen as the technological basis for the system, as this application was sufficiently functional to be able to map the chosen object-relational data model. In addition, the application could be installed on all desktop computers without any problems. Local synchronisation of the data within the excavation network was possible and FileMaker also offered a server component for online operation and synchronisation via the Internet.

The modular structure chosen was supposed to make it possible to offer a uniform data model at the core, which could be supplemented with project-specific extensions. In practice, however, these adjustments turned out to be very time-consuming, as changes made during the project phase always had to be transferred back to the master clone and then to the other project copies. The use of proprietary software also posed a problem. For example, software changes were not always backwards compatible. Therefore, the switch to a newer version also required a migration of the data. Additionally, desktop and server licences for numerous excavation computers represented a considerable financial expense. Finally, the use of proprietary software contradicted the open source idea to which the DAI-IT is committed.

Despite these problems, the Filemaker version of iDAI.field had been used relatively successfully by more than 35 projects at DAI. This showed the demand for an excavation software that could meet the requirements of the DAI. At the end of 2009 it was therefore decided to address the problems that had been identified and to develop a new database solution based on common web technologies. For this purpose, the DAI cooperated with the Brandenburg University of Technology Cottbus-Senftenberg, which had developed the Cottbus Information System for Archaeology and Building Research (CISAR), also an application for documenting archaeological field research (Henze *et al.* 2013; Schäfer *et al.* 2013).

The medium-term goal was to combine the respective strengths of CISAR and iDAI.field in one system and to make this available as a free, web-based successor solution (working title: OpenInfRA). Overall, the scope of the application to be developed was very ambitious and covered almost all possible application areas of archaeological fieldwork including GIS, 3D and much more. The project was pursued until 2016, while at the same time the first version of iDAI.field continued to be used. Unfortunately, the results were almost exclusively theoretical. A functional application has not been developed. Therefore, in 2016, it was decided at DAI to start a new project and develop the application from scratch (Fig. 2). The specifications were:

– a generic data model that can deal with most documentation requirements of archaeological fieldwork while also trying to maintain standardisation where possible;

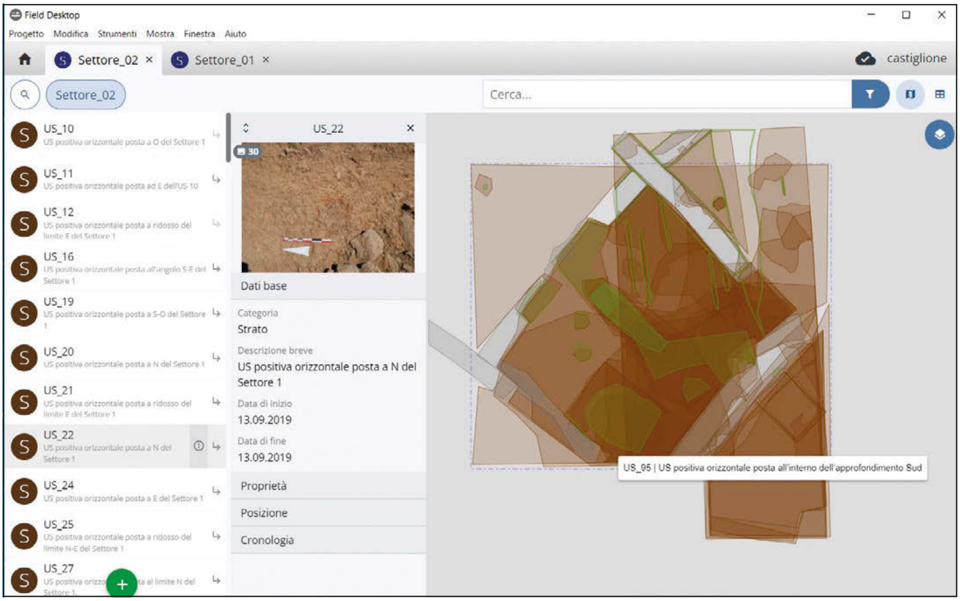


Fig. 2 – The current version of iDAI.field: 3.0. Screenshot of the application with data from the excavation project in Vetulonia/Castiglione della Pescaia of the Rome Department of the German Archaeological Institute.

– to support distributed work and data entry in the field even in places with no Internet coverage (need for a very robust synchronisation between the clients and the server);
– the integration of spatial data and descriptive documentation;
– to use only widely used open source technologies;
– to offer a low technical barrier and general ease-of-use (no high barrier of entry due to the technical complexities involved in setting up web servers and databases and configuring the respective software stack);
– and as a goal with lower priority: to later extend the application further to also feature a meta-search that will enable cross-project queries.

## 3. Technology

From the very beginning, the application has been based entirely on open source web technologies. The main application is written in TypeScript and uses established open source frameworks such as Angular and Leaflet. One advantage of this approach is that the functionality and layout of the application only have to be implemented once and are then available identically (with minor adjustments) on all supported operating systems (Windows, macOS and Linux). Another advantage is that parts of the code could be more easily reused in the supplementary web publishing platform iDAI.field web.

By using the electron framework (https://www.electronjs.org/), the application can be delivered as a single installable desktop application without additional dependencies. To enable robust support for offline work with later syncing between researchers, the Javascript database PouchDB (https://pouchdb.com/) is used. PouchDB is a browser variant of the NoSQL database Apache CouchDB. The central feature of both CouchDB (https://couchdb.apache.org/) and PouchDB is the ability to replicate: the state of one database can be transferred to another one. This replication can also be automated continuously between databases (synchronisation), which is the core functionality used for iDAI.field. The desktop application can be used online and offline – alone or connected to installations of the software on other computers.

Another argument for using PouchDB was the fact that a NoSQL database works great with user-configurable data models. iDAI.field's data model should, on the one hand, be based on the foundation of a fixed core data model common to all projects to enable comparability of data across project boundaries. On the other hand, it should also allow for project-specific customization that would have been more difficult to support with an SQL database. By using PouchDB, documents can be easily modelled and stored as JSON objects with arbitrary fields. The structure of these JSON objects is stored within the project configuration, which also exists as a document in the database.

## 4. Data model

In iDAI.field, each entity is a resource belonging to a specific category (e.g. "Stratigraphic unit", "Find", "Image"). Resources are described by a set of fields and linked with each other via relations (e.g. hierarchical, temporal or spatial relations). The project configuration determines which categories are available for selection in a project and which fields can be filled in depending on the category. The configuration is composed of three different parts, each fulfilling a specific role between the poles of comparability and adaptability.

The core configuration defines the framework within which all iDAI.field projects operate. Here, the main categories (e.g. "Find") as well as their possible linkings via relations among each other are defined, furthermore the most important fields that are directly referenced in the application code (e.g. "identifier", "geometry"). The library contains a number of subcategories (e.g. "Pottery" as a subcategory of "Find") and fields for a further description. The fields were chosen by evaluating projects created with iDAI.field 1 and identifying the most commonly used fields for each category. The use of the library is not mandatory but should motivate users to reuse existing categories and fields instead of always creating new ones. Therefore, it is planned to gradually extend the library in the future using the configuration data of existing projects. Finally, the project-specific subcategories and fields can be created to meet the unique requirements of a project. Data entered in these can therefore only be compared with those of other projects to a limited extent. However, it is also planned to incorporate a curated selection of project-specific configuration elements to the library and thus make them available to all users.

## 5. Features

iDAI.field currently consists of three different software components: the desktop application Field Desktop for entering data, the server application FieldHub – providing a centralised synchronisation target – and the web platform iDAI.field web for publishing the data. Field Desktop is the main component of iDAI.field, where most of the development work has gone into. The main functionalities of the application include:

– Database and file synchronisation between individual desktop clients via HTTP, mainly used within local WiFi or LAN on excavation.
– A comprehensive resource management with a hierarchical view as well as basic search capabilities (full-text search for specific core fields, field specific search).

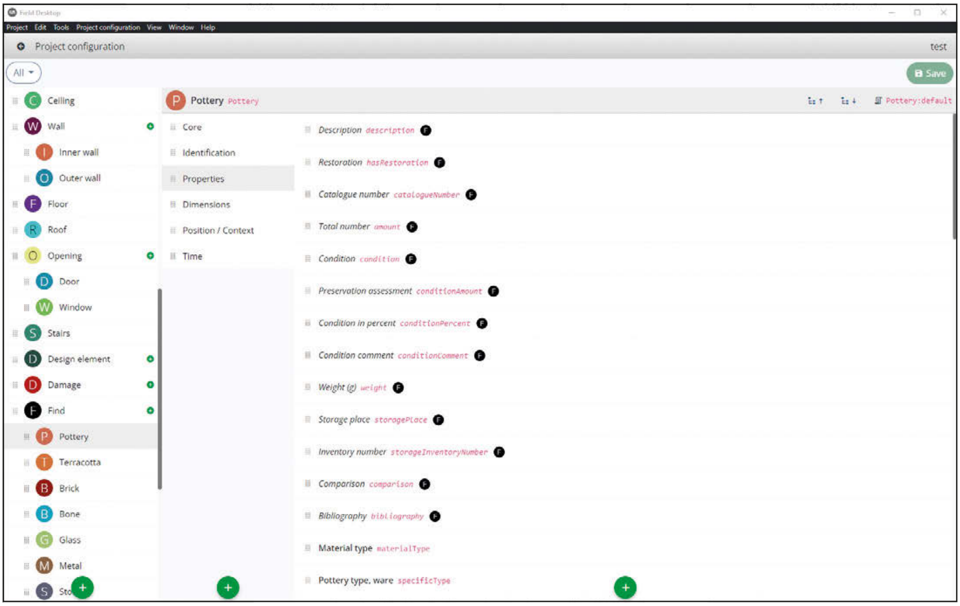


Fig. 3 – Screenshot of the iDAI.field 3.0 configuration editor.

– Integration of geodata into the application and the joint display of geodata with the respective resource data.
– Image management: Images can be imported into the application, linked to resources and displayed as map layers after adding georeferencing information by importing a world file.
– Type management: Types can be sorted hierarchically in catalogues and linked to finds.
– A configuration editor for an easy customization of the project configuration, including a value list editor (Fig. 3).
– A simple matrix view, which is automatically generated from the project data depending on the temporal or spatial relations set for the resources (the matrix view is implemented in a simplistic way and needs to be revised in the future.).
– Import and export of project data in the formats CSV, GeoJSON and Shapefile; furthermore there is the possibility to export or import type catalogues including all images.
– Creation and recovery of project backup files.
– Multi language support: with version 3.1, data can be entered in different languages per field; the user interface is available in English, German, Italian and Ukrainian.

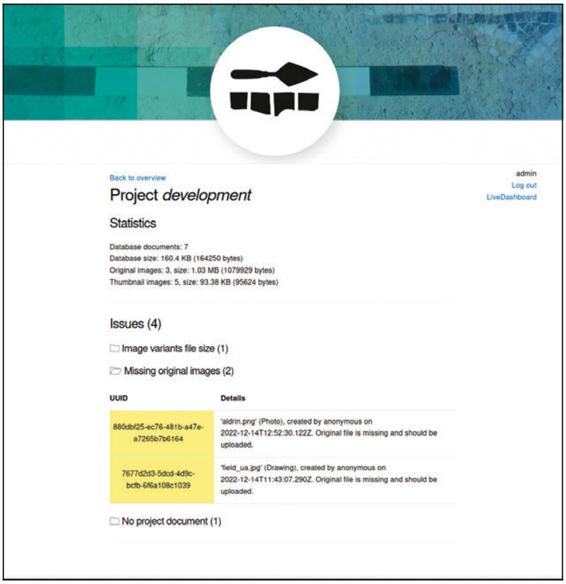


Fig. 4 – Screenshot of the FieldHub data monitoring interface.

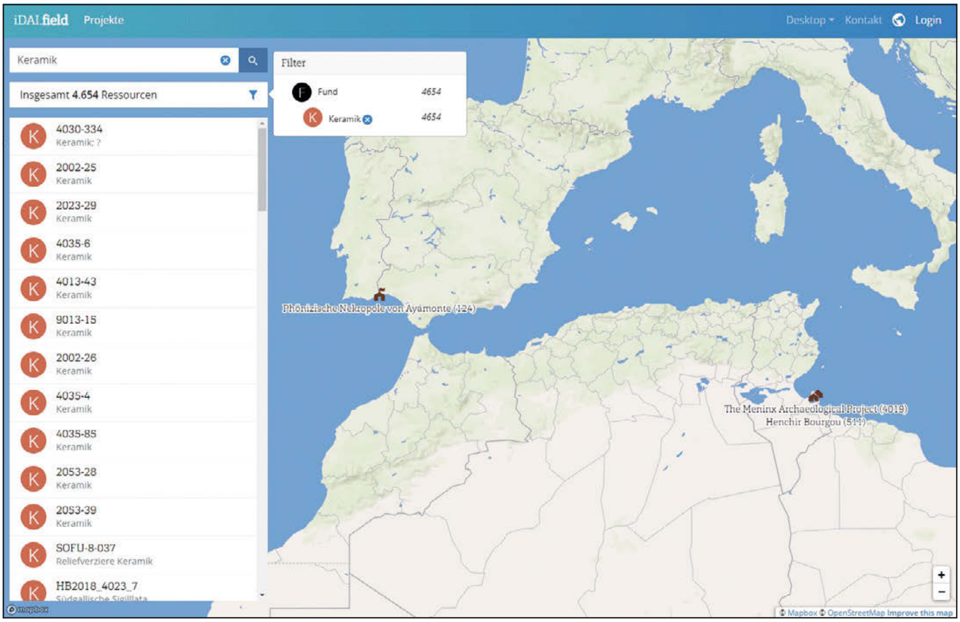


Fig. 5 – Screenshot of iDAI.field web with cross-project search for ceramic finds.

FieldHub is a small server application, written in Elixir, that institutions may provide for their researchers as a permanent syncing target and to collect all data by all running projects centrally (Fig. 4). FieldHub can be deployed using pre-built Docker images we host on our GitHub container registry (https://github.com/dainst/idai-field/pkgs/container/field_hub). The server provides some monitoring that enables project members to track issues (for example if someone did not upload all their high resolution images to the server, which would be essential for later publications).

iDAI.field Web is the DAI publication platform written in Elixir (backend) and React (frontend) for projects created with Field Desktop (Fig. 5). It provides an overview of all published projects on a world map and allows submitting search requests across these projects. The possibilities of the common core data model are already being used to some extent in the form of a cross-project search with the option of filtering by category. These search options are to be further expanded in the future. Currently iDAI.field Web still contains some dependencies on the DAI's infrastructure, which will have to be refactored in order to make it usable for an audience outside the DAI.

## 6. Development methodology

In the development of the Field software, an agile approach with two-week sprints has been implemented. Already at a very early stage in development, a pre-release version of the application was used by archaeological excavation projects (such as the Meninx Archaeological Project: https://field.idai.world/project/meninx-project); their feedback was then used for the further development of the application in the next iteration. This approach ensured that the application would not be developed past the needs of its users and could be used productively in the field.

In order to cope with the foreseeable increasing complexity of the application, it has been written according to Clean Code principles based on the guidelines of Robert C. Martin (2009) to keep it as intuitively understandable as possible. This includes frequent refactorings and code reviews. In addition, an extensive test suite with currently about 900 unit tests and about 140 end-to-end tests ensures that no functionalities are lost. While the end-to-end tests in particular involve a great deal of maintenance work because they have to be adapted constantly, they have also proven very effective in preventing errors.

Although the different software components also differ technologically, some parts of the code are currently being reused by multiple components. For example, one of the most important core components of the application, which is responsible for loading the project configuration, is currently used in Field Desktop as well as in the backend of iDAI.field Web and in the prototype of the mobile application. To simplify this process, all components reside in a single code repository.

## 7. Open source development

Since its redevelopment with version 2, iDAI.field has relied exclusively on open source libraries and has been published on GitHub as an open source project under the Apache License 2.0. However, the application was initially only used by excavation projects of the DAI and other institutions that are in close contact with the DAI. To work with a customised project configuration, a JSON file had to be created and submitted to the developers, which was then deposited in the GitHub repository and shipped with a new version of the desktop application.

With version 3.0, released in spring 2022, several steps have now been taken towards opening up iDAI.field. Project configurations are stored in the database itself and can be created and edited in a configuration editor integrated into the desktop application, so that consultation with the DAI is no longer necessary to use the software. Nevertheless, certain dependencies still remain. The library refers to DAI systems such as iDAI.gazetteer and iDAI.bibliography, and the publication platform iDAI.field Web, as part of the iDAI.world, cannot easily be set up in other contexts (unlike Field Desktop and FieldHub). The goal is to further resolve these dependencies in the future and turn Field into a "true" open source project that is jointly developed and used by a range of different institutions and individuals.

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## ABSTRACT

The German Archaeological Institute (Deutsches Archäologisches Institut, DAI) conducts a variety of different types of field research, each with its own unique documentation requirements: excavations, surveys and architectural surveys. The resulting differences are reflected in the workflows, the recording methods and the documentation. In addition, the DAI's international work has to comply with the guidelines of the respective heritage agencies in the host countries. iDAI.field is the system for documenting archaeological fieldwork at the DAI. From the very beginning it was developed to meet these very different requirements. The development spanned several years, major versions and associated, far-reaching technology changes. The latest iteration of the application relies exclusively on open source technologies and is published on GitHub under the Apache License 2.0 in accordance with DAI-IT's open source policy. In order to open up the application to other interested researchers and/or developers, the focus of the last year has been the implementation of an extended configuration interface and the removal of dependencies from the DAI infrastructure. This article outlines the development history, introduces the currently available functionalities, and briefly discusses the data model, followed by an overview of the technologies used. It also describes the development into a real open source product and gives a short outlook on the future plans.

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# PUNTO ZERO, UNA NUOVA WEB APPLICATION PER LA GESTIONE E L'INFORMATIZZAZIONE DEI DATI DI ARCHIVIO. IL CASO DI ANCONA

## 1. Introduzione

L'oggetto di questo contributo è frutto di un lavoro congiunto tra l'Università di Bologna e la Soprintendenza Archeologia, Belle Arti e Paesaggio delle Marche, nato per colmare la mancanza di una visione sistematica e critica di tutti i dati archeologici della città di Ancona, informazioni che risiedono già stratificate negli archivi della Soprintendenza, ma che spesso non vengono messe a sistema e collegate l'una con l'altra, archiviate in sezioni diverse come quella amministrativa, dei dossier, dei diari di scavo, dei rilievi o nel catalogo fotografico, una divisione che ovviamente segue normalmente la natura del dato, ma che nel tempo può generare un distacco tra le diverse fonti.

Una lacuna che era stata in parte colmata sia dall'eccellente lavoro di S. Sebastiani (1995), lavoro che comunque necessita un aggiornamento a oltre vent'anni dalla sua pubblicazione, sia da altri contributi di sintesi (Baldoni 2020; Sapone 2021) che infine da interventi specifici, come il volume di M. Salvini relativo agli scavi dei magazzini del porto romano ubicati sul lungomare Vanvitelli (Salvini 2014; e anche Colivicchi 2002; Paci 2021).

Per quanto riguarda la città di Ancona, ad eccezione degli interventi relativamente recenti, buona parte della documentazione è conservata in fogli cartacei suddivisi in diversi faldoni catalogati secondo un ordine topografico. Per questo motivo, il primo passaggio del lavoro è consistito nell'acquisizione in formato raster con risoluzione a 300 dpi di tutti i documenti relativi alla città per un totale di circa 12.000 file, distribuiti nelle varie sezioni sopra citate. Per quanto riguarda i documenti più datati, soprattutto quelli pertinenti all'archivio storico, è stata fatta una rilettura complessiva dei singoli faldoni, spesso scritti a mano, mentre per gli altri documenti è stato utilizzato Tesseract.js, un porting in Javascript della libreria Tesseract (https://tesseract.projectnaptha.com/) per il riconoscimento ottico dei caratteri (OCR), in modo da avere dei file testuali leggibili dalla macchina. Una volta terminata la fase di digitalizzazione, per gestire e catalogare tutte le informazioni note, suddivise in 280 cartelle e relative a 205 siti archeologici di varia natura e cronologia, è stata sviluppata una web application denominata Punto Zero, collegata ad un sistema webGIS che funge da piattaforma cartografica per la visualizzazione e la navigazione della Carta Archeologica online (Fig. 1).

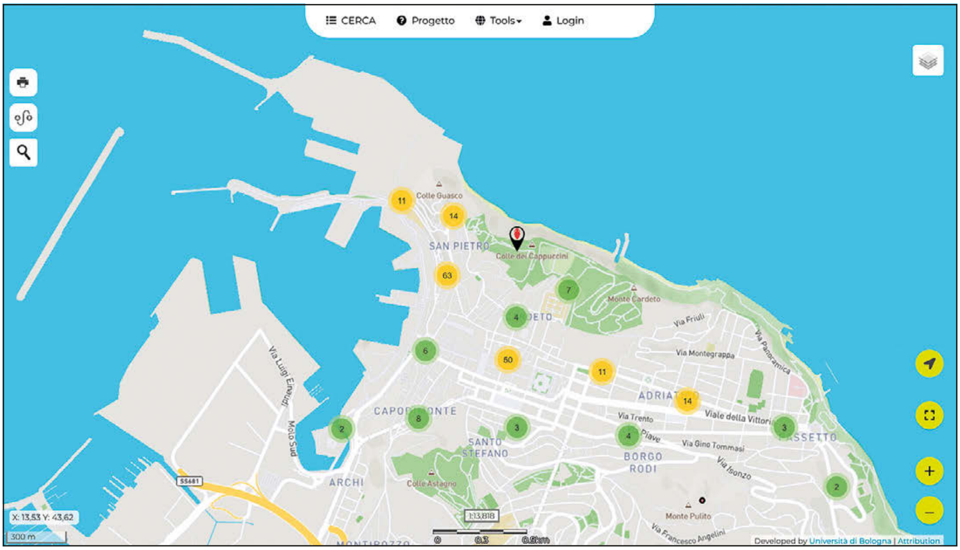


Fig. 1 – Carta archeologica con visualizzazione dei punti di interesse.

## 2. La web application

In breve, la webApp è stata sviluppata con una interfaccia lato client costruita con una dashboard costruita con il framework Boostrap 5 (https://getbootstrap.com/) e realizzata con i linguaggi di programmazione HTML, CSS e JavaScript. Mentre dal punto di vista server, il linguaggio di programmazione utilizzato è PHP, grazie al quale è possibile aggiornare dinamicamente i dati della webApp, contenuti in un database PostgreSQL. La natura peculiare dei dati archivistici e la necessità di avere degli strumenti personalizzati per il collegamento con la piattaforma SIGECweb (http://www.catalogo.beniculturali.it) hanno portato a preferire la realizzazione di una applicazione *ex novo* rispetto all'uso di software open source già disponibili per la condivisione dei dati spaziali, come Geonode (https://geonode.org/) o Geonetwork (https://geonetwork-opensource.org/).

La prima fase di sviluppo si è concentrata sull'impostazione dell'area amministrativa e dell'architettura logica della banca dati per l'archiviazione dei dati digitalizzati. Il database (Fig. 2) è costituito da numerose tabelle, tra cui le principali sono quelle relative ai Siti Archeologici, alla memorizzazione delle informazioni dell'Archivio Documenti, Archivio Disegni, Archivio Foto e Strutture. La tabella Siti Archeologici si compone di tutti i campi richiesti dall'ICCD per la compilazione della Scheda Sito 3.0 ed è in relazione una a molti con le tabelle Cronologia, Indagini, Campioni, Analisi, Relazioni

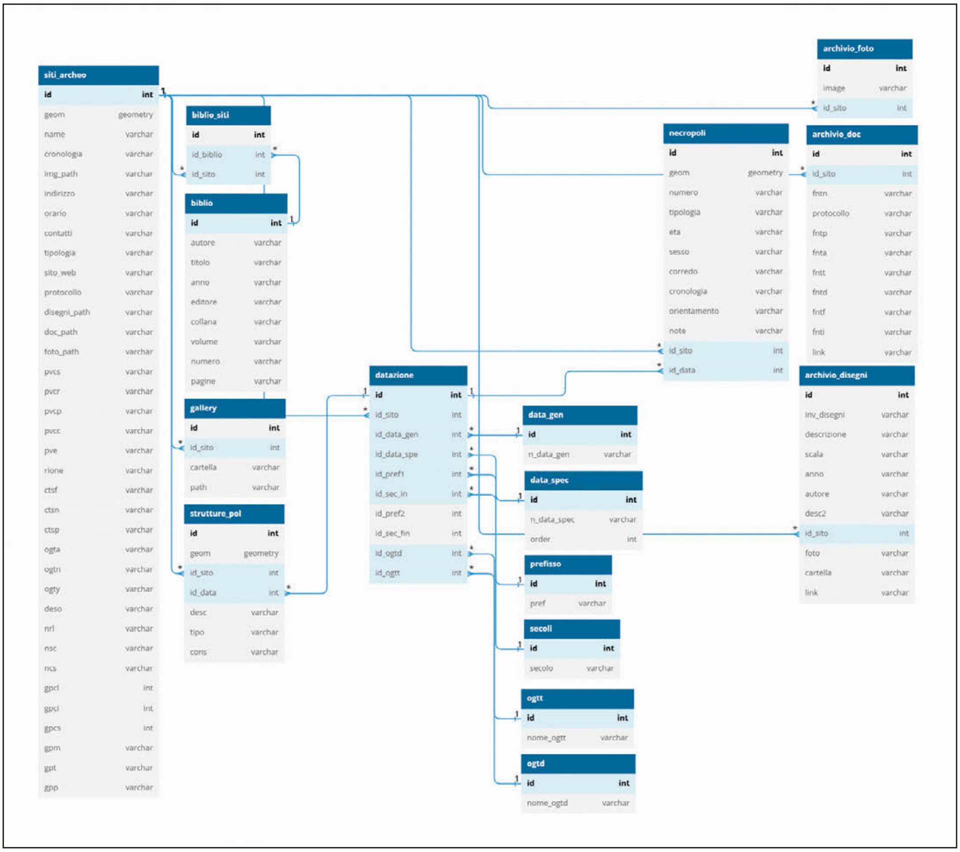


Fig. 2 – DB Entity Relationship Diagram (ERD).

con altri contesti, Bibliografia e Quote. Oltre a queste ovviamente vi sono altre tabelle relative ai *thesauri* definiti dal Catalogo. La webApp ha una parte pubblica, accessibile senza richiesta di autenticazione a tutti gli utenti ed un'area di amministrazione riservata, accessibile solo ai responsabili che hanno l'autorizzazione all'inserimento e alla modifica dei dati.

La parte amministrativa (Fig. 3) è costituita da diverse sezioni: Siti Archeologici, Archivio Amministrativo, Archivio Disegni, Archivio Documentazione, Archivio Fotografico, Bibliografia e Gestione Utenti. La sezione Siti Archeologici è formata da una serie di informazioni generali riguardanti la localizzazione del sito, la sua georeferenziazione e la descrizione. Nell'area Documentazione vengono elencati tutti i record collegati a quel determinato sito provenienti dall'Archivio Disegni, dall'Archivio Foto e da quello

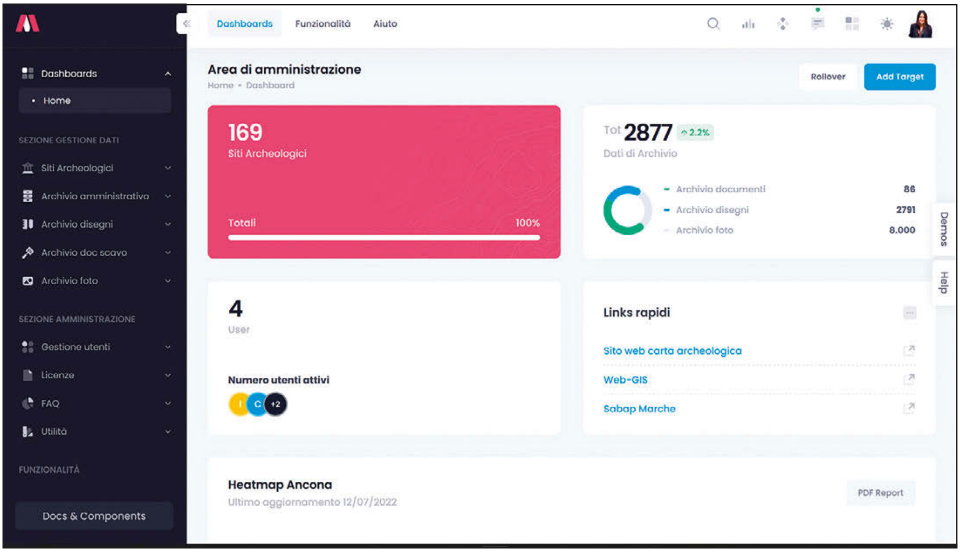


Fig. 3 – Area di amministrazione del sistema.

amministrativo; dunque è possibile vedere per ogni contesto quanti disegni sono disponibili in archivio, averne la descrizione, l'anno di realizzazione, il nome dell'esecutore, il numero di riferimento archivistico e consultare direttamente la scansione del documento.

La scheda sito è composta inoltre da due importanti sezioni, la prima riguardante la cronologia e l'altra le quote. Queste sono intimamente collegate alla piattaforma GIS, poiché in funzione della scelta cronologica che verrà effettuata sulla scheda, in automatico la visualizzazione della carta archeologica di quel contesto assumerà il colore relativo alle varie fasi per ciascun elemento digitalizzato e anche le texture si adegueranno al tipo di classificazione scelta. Per quanto riguarda la cronologia, per ogni sito è possibile avere un inserimento plurimo nel quale indicare la datazione generica, quella specifica, al secolo e le destinazioni d'uso. In questo modo, per i contesti pluristratificati, frequenti in ambito urbano, balza subito evidente la sequenza cronologica e i cambiamenti che un determinato edificio ha subìto nel tempo, con ampliamenti, ridefinizione degli spazi e variazioni nello sfruttamento di determinate aree urbane.

Allo stesso modo ogni contesto ha la possibilità di avere un inserimento plurimo delle quote, specificando a cosa si riferisce il dato (ad es., cresta muraria, pavimento, piano di calpestio, etc.). I dati relativi ai piani sono automaticamente utilizzati dal sistema per creare il DTM (Digital Terrain Model) della città. Più quote saranno inserite nella webApp più il sistema sarà

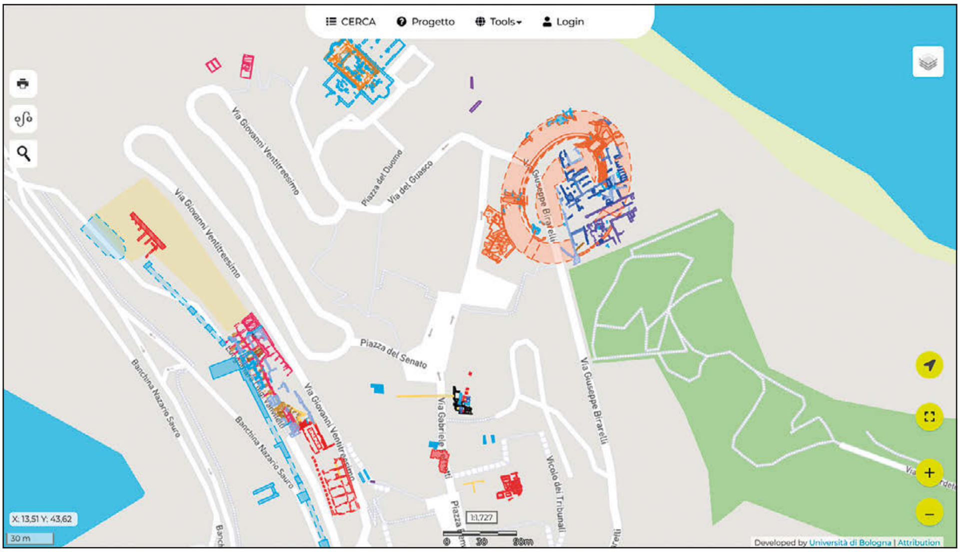


Fig. 4 – Carta archeologica con visualizzazione delle planimetrie digitalizzate riferibili ai singoli contesti.

in grado di affinare la creazione della superficie topografica antica relativa alle diverse fasi cronologiche.

Per quanto riguarda la costruzione della carta archeologica, sono state preliminarmente scansionate tutte le planimetrie relative ai singoli contesti presenti nell'Archivio Disegni della Soprintendenza. Ogni documento è stato georiferito, per poter poi avviare l'operazione di editing, che è stato realizzato con il software open source QGIS (3.16), mediante il quale è stato possibile ridisegnare ogni singolo elemento presente all'interno dei disegni. Ogni elemento è stato collegato poi al contesto di provenienza, alla datazione generica e specifica e alla sua tipologia (muro, pavimento, mosaico, strada basolata, colonna, canaletta, etc.): pochi dati, che tuttavia consentono di creare una cartografia online, utilizzando la libreria Javascript Leaflet (https://leafletjs.com/), che tenga conto di questi parametri per differenziare la visualizzazione degli elementi sulla carta.

Il sistema webGIS è costituito lato server dal software Geoserver (https://geoserver.org/), scritto in Java. Le query effettuate sul database restituiscono risultati elaborati come file GeoJSON, un formato aperto che consente di archiviare le primitive geometriche di tipo spaziale e i loro attributi descrivendoli attraverso il JSON (JavaScript Object Notation). Il formato GeoJSON viene successivamente letto dall'interfaccia cartografica lato utente, che come abbiamo visto, in questo caso è costituita dalla libreria Javascript Leaflet.

La carta archeologica online contiene sia un livello puntuale che riguarda, oltre ai siti archeologici più importanti, anche le indicazioni di ritrovamenti sporadici rinvenuti nel corso del tempo, sia un livello di lettura planimetrico (Fig. 4); infatti per quanto riguarda i contesti più noti e che possedevano un grado di documentazione tale da poter essere georiferiti con precisione, l'utente può visualizzarli in pianta, la quale presenta la caratterizzazione dei vari elementi architettonici, la loro datazione e descrizione, con l'ausilio di cambi cromatici per la comprensione delle differenti fasi cronologiche.

## 3. Verso una nuova comprensione urbanistica della città

La creazione di questa carta archeologica online pluristratificata, le cui informazioni sono riviste in chiave critica, aggiornate e messe a sistema con tutti i dati disponibili, consente di formulare nuove interessanti teorie sullo sviluppo urbanistico della città, sulla sua parte pubblica e quella residenziale, sull'organizzazione del suo importante porto, sullo sviluppo nel tempo delle necropoli e sulla viabilità. L'archiviazione delle quote relative ai piani di calpestio documentate nei vari contesti, come è esemplificato nella descrizione della parte amministrativa della webApp, ci ha aiutato a modellare diversi DTM per le varie fasi cronologiche, basati sui dati archeologici, poiché la visione attuale è stata sicuramente compromessa non solo dalle successive fasi insediative, ma anche dai pesanti bombardamenti subiti dalla città durante la seconda guerra mondiale. Una catastrofe che tuttavia ha consentito di indagare, durante la fase di ricostruzione negli anni '50, numerosi e importanti ritrovamenti archeologici, i quali però spesso sono documentati solo attraverso la restituzione grafica e fotografica, a cui solo in pochi casi è allegata una breve descrizione delle emergenze rinvenute. Questo ha comportato una grave perdita di dati, recuperabili in parte con il riposizionamento dei rilievi dell'epoca confrontati con i dati più recenti, che completano un puzzle altrimenti frammentato e di difficile lettura.

In questa rivalutazione critica dei rilievi archeologici dei singoli contesti è stato fondamentale non solo rivedere la corretta georeferenziazione delle planimetrie, ma anche armonizzare e riportare su quote assolute le informazioni contenute nei disegni e nella documentazione, dove esistenti. Possiamo proporre come caso esemplificativo lo studio dell'area compresa tra piazza Santa Maria e via Saffi (Fig. 5), una porzione cittadina che in epoca romana era caratterizzata dalla presenza di numerose strutture inquadrate all'interno di una maglia viaria, la quale consente di seguire l'andamento urbanistico relativo alla sistemazione di epoca imperiale dell'area portuale. Infatti il fronte mare anconetano era caratterizzato senza soluzione di continuità da una serie di strutture funzionali all'attività marittima, in particolare da magazzini e *navalia*. Come già noto, la viabilità seguiva un tracciato ad arco


Fig. 5 – L'area tra piazza Santa Maria e via Saffi.

lungo la costa, mantenendosi su un piano leggermente ascendente da S verso N, appena sotto al primo salto di quota che caratterizza le pendici collinari su cui si estende la città.

I resti di questa viabilità lungo costa sono stati rinvenuti lungo via della Loggia, largo della Dogana, via Saffi e durante gli scavi dei magazzini sul lungomare Vanvitelli. L'area tra piazza Santa Maria e via Saffi è stata oggetto di vari ritrovamenti succedutisi nel tempo e venuti alla luce in circostanze molto differenti. Ad esempio, i rinvenimenti più datati risalgono al 1929, quando durante i lavori per il collettore fognario vennero scoperti due lacerti di lastricato, il primo in via della Loggia presso la piazza antistante la chiesa di Santa Maria a circa -2.50 m dal piano stradale, che fu distrutto durante gli stessi scavi, e il secondo poco più avanti tra largo della Dogana e vicolo Foschi a quota -3.30 m rispetto al piano di campagna attuale. La situazione topografica di questa porzione di città in epoca romana si chiarifica ulteriormente nel 1957 durante i lavori di ristrutturazione di Palazzo Manciforte, in occasione dei quali venne scoperto ad una profondità di -4,65 m dal piano stradale un tratto di strada basolata di cui è stato identificato un solo lato, allineato con gli edifici limitrofi, per una larghezza complessiva stimata di circa 6 m.

Questo rinvenimento è molto importante perché dal punto di vista della viabilità vediamo che il basolato da un lato continua il tracciato già identificato in via della Loggia/largo della Dogana verso N proseguendo lungo via Aurelio Saffi e dall'altro vi è una sorta di ramificazione che porta la strada a proseguire idealmente lungo il tracciato del lungomare Vanvitelli. La conferma che il piano di calpestio romano si attesti in questa zona a circa 4 m al di sotto dell'attuale piano stradale (la cui quota assoluta oggi è di 5.17 m s.l.m.) è data da un rilievo redatto nel 1964, che descrive i rinvenimenti delle strutture di epoca romana scoperti durante alcuni lavori per lo scavo delle fondazioni per una abitazione in via Foschi. Il rilievo riporta nel dettaglio la misura delle singole murature, le caratteristiche costruttive, la presenza di pavimentazioni, la tipologia e la quota di riferimento ovvero -4.20 m rispetto al piano stradale. Pur non avendo una relazione a corredo del disegno, da questo si può dedurre che l'edificio possa essere interpretato come magazzino, composto da 5 vani stretti e allungati, paralleli tra loro, con pavimentazione in *opus spicatum*. Questi ambienti, alcuni dei quali intonacati, si affacciavano su un porticato, la cui presenza è testimoniata da alcune basi di colonne.

La localizzazione di questo edificio ci consente di apprezzare lo sfruttamento dei salti di quota naturali; infatti gli edifici sottostanti si sviluppano sul piano stradale ubicato lungo via Saffi, per una lunghezza complessiva che arriva fino al limite della parete naturale, così che il muro di fondo della struttura ha una doppia funzione, di chiusura e di sostegno. Al di sopra, sull'isoipsa dei 10 m s.l.m., si dispongono altri magazzini, documentati dal ritrovamento nella medesima occasione di cinque strutture murarie in *opus mixtum*, che vedono alternate alte fasce realizzate in blocchetti di pietra bianca del Conero malamente sbozzata con ricorsi di uno o due filari di mattoni posti di piatto. Il rinvenimento di una condotta fognaria, che correva a S degli edifici e parallela ad essi, suggerisce la presenza di una strada, la quale fiancheggiava questi edifici e li collegava con la viabilità posta lungo l'asse via della Loggia/largo della Dogana e via Saffi, da SE verso NE assecondando il declivio verso il mare.

I dati forniti da questi rilievi degli anni '60 sono stati confermati dai risultati di alcuni saggi archeologici preventivi effettuati in via Saffi, 12 nel 2001, grazie ai quali è stato possibile porre in luce due tratti di una medesima struttura muraria di epoca romana, con andamento SO-NE, larga 1,50 m e conservata in elevato per 0,65 m, caratterizzata da un nucleo in cementizio costituito da pietre calcaree legate con malta e paramento realizzato con pietre di differenti dimensioni e faccia regolare a vista. Il muro è stato individuato nell'ambiente più a monte ed era posto a una quota molto più elevata degli altri a circa 8 m s.l.m. in linea con i resti archeologici rinvenuti nel 1964.

Il proseguimento di queste indagini ha portato all'individuazione di altre strutture murarie poste a una quota più bassa (rasatura 5,3 m s.l.m.) pertinenti ad un vano quadrangolare, costituite da un nucleo in pietra calcarea legata da malta con paramento composto da pietre irregolari e angoli caratterizzati dall'utilizzo di ammorsamenti in laterizi.

## 4. Conclusioni

La webApp Punto Zero dunque è stata programmata per una gestione integrata del dato archeologico, considerando la sua complessità come oggetto di tutela, di valorizzazione, di studio, di programmazione urbanistica, ma anche come elemento di godibilità da parte di un pubblico più ampio, il quale attraverso questo strumento più intuitivo può comprendere il paesaggio urbano antico e le sue trasformazioni nel tempo, perché la città è un organismo in continua evoluzione. L'integrazione e la rilettura di tutti i dati archeologici di archivio, catalogati all'interno di una banca dati collegata ad una visualizzazione planimetrica sistematica pluristratificata, consentiranno uno studio diverso e più approfondito della topografia antica della città di Ancona, come si evince dal breve esempio qui proposto.

A pieno regime Punto Zero potrà dunque divenire strumento di supporto a complemento delle normali attività di tutela dell'ente pubblico per la gestione integrata dei dati archeologici già contenuti negli archivi della Soprintendenza Archeologia, Belle Arti e Paesaggio delle Marche e di nuova acquisizione, derivanti in particolare dalle attività di sorveglianza durante la realizzazione delle opere pubbliche. L'elasticità del sistema consente di applicarlo con estrema disinvoltura anche ad altri contesti urbani, in quanto la logica alla base della struttura software e l'utilizzo di standard catalografici nazionali svincolano il suo utilizzo rispetto ad uno specifico contesto. Attualmente la webApp relativa alla Carta Archeologica di Ancona non è disponibile online, poiché è in attesa della sua definitiva pubblicazione, tuttavia in parallelo si sta lavorando all'implementazione di altri strumenti e alla distribuzione del software con licenza MIT. I dati saranno parzialmente resi pubblici in quanto i documenti d'archivio contengono informazioni sensibili che non possono essere divulgate senza specifico permesso.

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## ABSTRACT

The case of city of Ancona highlighted the lack of specific software for the management and digitization of the archaeological data stored in the archives of the Superintendence. The archives contain many heterogeneous data that can help to understand the history of the archaeological sites, from their discovery up to the information archived from the numerous research or rescue archaeology excavations that have taken place over time. The normalization of all the archival data within a single relational database associated with their specific geographical nature, thanks to an overall view and an in-depth review of the data, shed new light on both edited contexts and archaeological evidence that had not yet received an adequate study and that had not been entered into a system that considers nearby data. This software does not replace existing cataloging systems, such as SIGECweb, but it aims to support the cataloging activity using the same standard and at the same time allowing the Superintendence to use the data for the protection activity and for their study.

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# LINKED OPEN OGHAM. HOW TO PUBLISH AND INTERLINK VARIOUS OGHAM DATA?

## 1. Introduction

ᚑᚌᚐᚋ (Ogham) stones (e.g. the Ogham stone CIIC 178 at Coumeenole North, located in the Com Dhíneol Thuaidh Townland, in the Barony of Corkaguiny, County Kerry, near Dunmore Head; Irish Townlands 2023), are monoliths with the early medieval primitive Irish Ogham script, mostly erected on the island of Ireland (Murray 2010, fig. 1; Schmidt *et al.* 2022, fig. 12) and in the western part of Britain between the 4th and 9th centuries. They are an important source for Archaic or Proto-Irish language and society. The letters of the Ogham alphabet consist of strokes written at different lengths and angles along (often natural) edges of the stones from the bottom left to the top and back down to the right. Names on the stones seem to be dedicated to a person. It remains unclear, however, whether the stones were grave markers, for example, or designated land ownership. Most of the stones are no longer at the original site, which is important for cartographic recording and makes it more difficult to determine their original function (Macalister 1945; MacManus 1997; Bogdani *et al.* 2021, 119-127; Schmidt, Thiery 2022).

The inscriptions consist of names (nomenclature words) such as CATTU (ᚉᚐᚈᚈᚒ; engl. battle) and relations (formula words) such as MAQI (ᚋᚐᚊᚔ; engl. son) to feature kinship or tribal relations. Ogham stones are mentioned in several catalogues such as books, e.g., Macalister (1945) known as CIIC, MacManus (1997) and O'Sullivan, Sheehan (1996), online databases, e.g., the Celtic Inscribed Stones Project (CISP) or online repositories, e.g., Ogham in 3D.

The density map in Schmidt, Thiery (2022, fig. 12) shows a cluster of Ogham stones on the Dingle and Iveragh peninsulas. The maps by Thiery (2023) also visualise clusters of Ogham stones in the counties of Kerry (153), Cork (92) and Waterford (51), distributed over the baronies Corkaguiny (mainly the Dingle Peninsula; 67), Iveragh and Dunkerron North (mainly the Iveragh Peninsula; 14/25), Magunihy (10) and Trughanacmy (15). A lot of the Ogham stones in this area are also standing in the landscape, so it is worthwhile to make a research trip there. The Linked Open Ogham Data Project was set up in 2019 by the Research Squirrel Engineers Network as a non-institutional funded use case which was also supported by the Wikimedia Germany Open Science Fellows Program in 2020/2021 as "Irish ᚑᚌᚐᚋ Stones in the Wikimedia Universe". In 2022 an

Fig. 1 – Ogham Stone at Dunmore Head (Irish: An Dún Mór), the westernmost point on the mainland of the island of Ireland (ph. F. Thiery); bottom right: OSM map of Ireland with the encircled Dingle Peninsula (Irish: Corca Dhuibhne) and the NE of the Iveragh Peninsula (Irish: Uíbh Ráthach), ODbL by OpenStreetMap contributors.

Ogham survey (Fig. 1) was done in Ireland by Florian and Peter Thiery, visiting Dublin, Cork, the Iveragh Peninsula and the Dingle Peninsula to record Ogham stones in the field and museums. The project aims at providing and integrating Ogham Data in community (Linked Data) hubs such as Wikidata and Open Street Map (OSM). Since graphs rely on linking statements between entities to form a network, this corpus is especially well-suited to being represented in a graph. This results in the sense of comprehensible and FAIR data in the RDF standard and Linked Open Data (LOD).

## 2. Ogham Data as Open Science

The hybrid Ogham LOD workflow (Fig. 2) is based on the idea of Open Science, Open Software, Open Data, and the FAIR principles to create re-usability and modular IT infrastructure with community standards and commonly used interfaces. The origin data will be digitised and transformed into CSV. In a data-driven approach, data modelling schemes (an Ontology and Wikidata Mapping Scheme) are created to transform the data into RDF

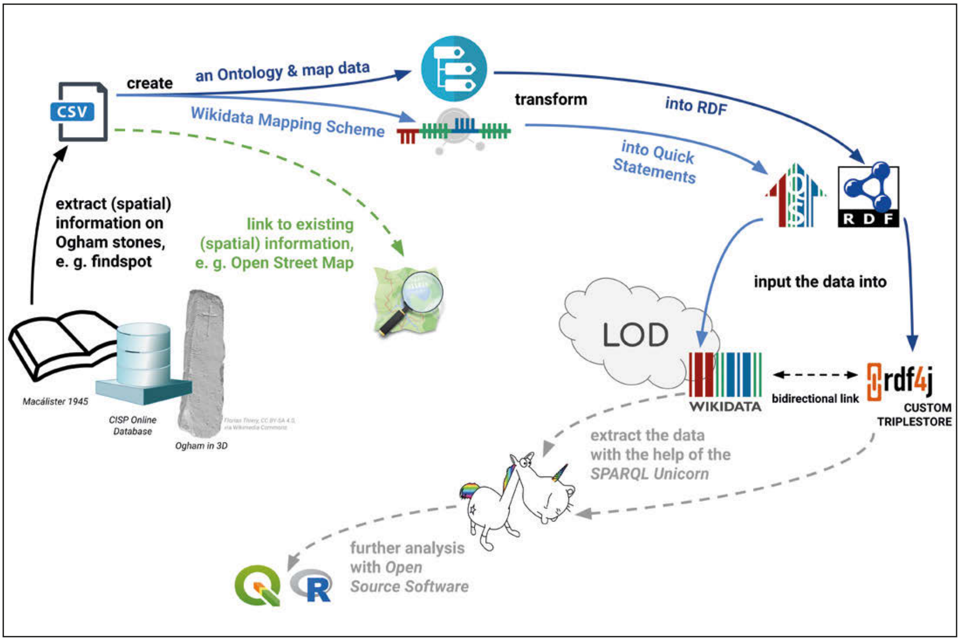


Fig. 2 – The hybrid Linked Open Data Ogham workflow (F. Thiery, T. Homburg, S.C. Schmidt, M. Trognitz, via Wikimedia Commons).

or Quick Statements using Python Scripts to allow iterations. The resulting data is then ready to import into an RDF4J Triplestore and Wikidata. The data is stored and published together with the scripts on GitHub, with a direct connection to Zenodo. With this Open Data and Open Research Software approach, citability and reproducibility by using GitHub and Zenodo with DOIs and CFF File are ensured; in Wikidata, a Project Page is used for documentation.

With the use of open source technologies and community standards such as RDF and Quick Statements, Ogham Data is available in several variants: i) as LOD in RDF in an RDF4J triplestore with a SPARQL endpoint and ii) inside Wikidata with its SPARQL query interface and its APIs. This allows for using the data in research software such as R or the SPARQLing Unicorn QGIS Plugin (Schmidt, Thiery 2022). Additionally, lightweight JavaScript Web Applications, aka Little Ogham Minions, are created to showcase the Ogham LOD: iii) a reference viewer (Ogham Link 2023a) to find similar catalogue numbers (e.g. O'Sullivan, Sheehan 1996, 908), and iv) an Ogham lookup tool (Ogham Link 2023b) to visualise the findspots on an interactive map.

## 3. Ogham in Open Street Map

Besides the community hub Wikidata, Ogham Stones should also be integrated into Open Street Map (OSM). Due to the high occurrences on the Dingle Peninsula, these stones are particularly suitable for doing so. In the South of Ireland, there are also Ogham stones in museum collections such as the University College Cork (UCC) Stone Corridor. This section provides examples of Ogham stones available "in the wild" in Ireland for visitors to view as cultural heritage. These archaeological artefacts have been partially scanned by the Ogham in 3D Project using 3D documentation techniques with the aid of strip light projection and are available as open 3D data. As mentioned before, the stones serve as an inscription carrier; the inscriptions consist of individual words that follow a formal logic. In OSM, the Ogham stones can be flagged by the tag "historic=ogham_stone" (B-unicycling, Fthierygeo 2023). This enables Ogham stones to have as uniform a structure as possible in OSM. This structure consists of a name, if possible, according to a system of literature, e.g. CIIC, the inscription engraved, Wikipedia articles, Wikidata entities, information on size, material descriptions, source information, as well as information on whether the stone is in its original location or has been moved (e.g. to a museum).

Squirrel Stone #178 (Q106680850) is part of the Coumeenoole North/Dunmore Head Ogham Site (Q85395557) as part of the Com Dhíneol Thuaidh Townlands in the Barony of Corkaguiny, County of Kerry (Fig. 3, left). The Ogham stone also has other identifiers: CIIC 178 (Macalister 1945, 170) and CISP~COUME/1. The stone stands on the picturesque coast of Ireland near Dunmore Head (An Dún Mór), the westernmost point on the mainland of the island of Ireland. On its discovery, Macalister writes: «This stone was lying prostrate on the summit of the promontory called Dunmore Head, when discovered by the Cork antiquaries Windele, Abell, and Horgan, in 1838; and was re-erected in the following year by a local priest, Rev. J. Casey» (Macalister 1945, 170). The stone bears the inscription ERC MAQI MAQI-ERCIAS MU DOVINIA. This contains names and so-called "formula words": MAQI and MU. MAQI is the most frequently found formulary word and can be translated as "son" (MacManus 1997, §6.27, 119). MU, according to Macalister (1945), is apparently an abbreviation for MAQI MUCOI (MacManus 1997, 171). MUCOI is another formula word meaning "túath", tribe (MacManus 1997, §6.27, 119-120), so X MAQI MUCOI Y can be translated as X son of the tribe Y (MacManus 1997, §6.27 119-120). According to the CISP entry, the names (possibly of persons) ERC, MAQI-ERCIAS and DOVINIA can be read in the inscription. ERC refers


Fig. 3 – Left: Ogham Stone CIIC 178 at Coumeenole North / Dunmore Head (Irish: An Dún Mór); right: Ogham Stone CIIC 187 at Kilmalkedar Church (Irish: Cill Maoilchéadair) (ph. F. Thiery); bottom: OSM maps, ODbL by OpenStreetMap contributors.

to a short name (MacManus 1997, §6.2, 101-102) with a reference to the divine (MacManus 1997, §6.5, 103), en. ~heaven. MAQI-ERCIAS refers to a category of names that use MAQI- as a prefix (MacManus 1997, §6.14, 108-109).

This name can also be observed on stone #125 (CIIC 125, CISP~ROVMO/2, Q106680787), as part of the Rooves More Ogham Site (Q85394017) in the townland of the same name in the Barony of East Muskerry, in the County of Cork. This Ogham stone bears the inscription MAQI-ERCIAS MAQI VALAMNI, translated roughly MAQI-ERCIAS son of VALAMNI. DOVINIA is a compound name of prefix and noun (MacManus 1997, §6.9, 105). This also occurs on stone #175 (CIIC 175, CISP~BRHAM/1, Q106680846) found at the Burnham East Ogham Site, with the townland of the same name in the Barony of Corkaguiny, in the County of Kerry. This Ogham stone bears the inscription MAQQI-ERCCIAS MAQQI MUCOI DOVINIA, translated roughly MAQQI-ERCCIAS son of the tribe DOVINIA. The inscription ERC MAQI MAQI-ERCIAS MU DOVINIA could thus be translated as ERC son of MAQI-ERCIAS son of the tribe DOVINIA (according to O3D: of Erc son of Mac-Erce descendant? of Duibne). Since DOVINIA is mentioned as a tribe on both #178 and #175, there could be a connection here. The same applies to MAQI-ERCIAS, which can be read on #178 and #125; moreover, #175 shows the name MAQQI-ERCCIAS. Here, however, it is not possible to confirm that it is the same entity. The Ogham Stone #178 has many identifiers on the web and is also available on OSM as node 5145413640.

Squirrel Stone #187 (Q106680860) is part of the Kilmalkedar Ogham Site (Q85395528) as part of the townland of the same name in Barony Corkaguiny, County Kerry (Fig. 3, right). The Ogham stone also has other identifiers: CIIC 187 (Macalister 1945, 181) and CISP~KMKDR/3. The Ogham stone stands in a graveyard outside the entrance to the ruined Romanesque church of Kilmalkedar (Irish: Cill Maoilchéadair). The ruin also contains an Alphabet Stone inscribed with DNI (*domini*) and the Latin alphabet in uncial script, which was carved around 550-600 AD (Corca Dhuibhne 3D 2023). The Ogham stone is characterised in particular by the fact that it has a cube-shaped pierced hole in the upper part (Macalister 1945, 181). The stone bears the inscription ANM MAILE-INBIR MACI BROCANN. This can be divided into formula words and names. The inscription bears the formula word ANM and MACI. MACI can be seen as a variant of MAQI. ANM can be translated as “name” (MacManus 1997, §6.27, 118) to indicate that it is the name of a person. The inscription also bears the names MAILE-INBIR and BROCANN, which are not recorded on any other known Ogham Stone (according to the CISP database). The inscription ANM MAILE-INBIR MACI BROCANN could therefore be translated as the name MAILE-INBIR son of BROCANN (O3D: name/inscription of Máel-Inbher son of Broccán). The Ogham Stone #187 has many identifiers on the web and is also available in OSM as node 9110402648.

Squirrel Stone #242 (Q106680977) is part of the Parkavonear Ogham Site (Q85396972) as part of the townland of the same name in Barony Magunihy, County Kerry (Fig. 4, left). The Ogham Stone has other identifiers: CIIC 242 (Macalister 1945, 237) and CISP~PARAR/1. The ruins of a church, or cathedral, Aghadoe (Irish: Achadh Deo), stand in this townland. The original location of the Ogham Stone was to the Southwest of the church. Today, the Ogham Stone is located on the top of the southern wall of the choir of church between a crucifixion plaque to the E and an architectural fragment to the W. The stone bears the inscription BRRUANANN, which describes a name (transliteration according to O3D: “of Brénainn” or “of Brénán”) that is not otherwise recorded in the CISP database. The Ogham Stone #242 has many identifiers on the web and is also available in OSM as node 10040757680.


Fig. 4 – Left: Ogham Stone CIIC 242 at Aghadoe Church (Irish: Achadh Deo); right: Ogham Stones CIIC 141 and 142 at Aglish Burial Ground (ph. F. Thiery), bottom: OSM maps, ODbL by OpenStreetMap contributors.

Squirrel Stones #141 (Q106680806) and #142 (Q106680808) are part of the Aglish Ogham Site as part of the Aglish Townland in the Barony of Corkaguiny, County of Kerry (Fig. 4, right). The Ogham stones have other identifiers: CIIC 141 (Macalister 1945, 137-138), CISP~AGLIS/1 (Macalister 1945, 138-139) and CISP~AGLIS/2. #141 «bears a Maltese cross within a circle, beneath which is a spear or arrow-like motif flanked on either side by a swastika» (Cuppage, Bennett 1986, 258) and the inscription MAQI MAQ[I-...O]GGODIKA described with OSM node 10041491619. #142 is hidden in the graveyard, and contains the inscription --]CELI AVI VU[D!--- that can be transcribed to [--] the client of the descendant of Vu[--] and can be described with OSM node 10041927343.

The Stone Corridor (Fig. 5, bottom left) at University College Cork (UCC, Fig. 5, top left) contains 28 Ogham stones, which are available to the public. One is Squirrel Stone #86 (Q106680741) with the UCC ID 18. This was originally part (number 11) of the Ballyknock Ogham Site, which


Fig. 5 – Top left: University College Cork (UCC); left middle and right: UCC Stone Corridor and Ogham Stone 86 / UCC 18, Ogham Stones owned by UCC, located at 51°53’37.3”N 8°29’32.1”W (ph. F. Thiery).

contains 15 Ogham stones (http://lod.ogham.link/data/OS40000031) in the Barony of Kinatalloon, County Cork. The Ogham Stone has other identifiers: CIIC 86 (Macalister 1945, 86) and CISP~BAKNK/5, as well as OSM node 10560404607. This Ogham Stone carries the inscription CLIUCOANAS MAQI MAQI-TRENI. The first name is unusual but could stand for CUNA (hound), Old Irish cú. The last name is well-known as Mac-Tréoin, the second part being like Old Irish trén (strongmen, warrior). Looking at the CISP database, the name “maqitreni” is also mentioned on CLMOR/1 (CIIC 15, Clonmore, Ireland) as “Maqi--Treni” but also on Ogham stones located in Wales on TCSTL/1 (CIIC 341, Wales, Llywell, SN 8700 2900, GB) as, “Maqitreni“ and on CILGN/1 (CIIC 428, Wales, Cilgerran, SN 1096 4305 GB) as “Maqi-Treni” which leads to the idea that persons named after a “trén” do not only appear on the Irish Island.

## 4. Outlook

Nevertheless, this concept and architecture cause problems in IT sustainability and hosting of resources for all non-institutional funded projects. The data can be maintained by archaeologists or Citizen Scientists GitHub Pull Requests (PRs) and Wikidata edits and is connected via bidirectional links between LOD and Wikidata. But how can we solve the IT challenges? In the Ogham case, we try to use the "Squirrel Power" and the Research Squirrel Engineers Network to create a community of enthusiasts and looking forward.

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ABSTRACT

The Linked Open Ogham Data Project was set up in 2019 by the Research Squirrel Engineers Network and supported by the Wikimedia Germany Open Science Fellows Program in 2020/2021. In 2022 an Ogham survey was done in Ireland to record Ogham stones in the field and museums. The project aims at providing and integrating Ogham Data in community hubs such as Wikidata and Open Street Map (OSM). This paper shows a hybrid Ogham LOD workflow, based on the idea of Open Science, Open Software, Open Data and the FAIR principles to create re-usability and modular IT infrastructure with community standards and commonly-used interfaces. Furthermore, the paper shows examples of Ogham stones from the Dingle and Iveragh Peninsulas in OSM and gives a deeper insight into the inscriptions and mentioned Ogham-specific formula words and names.

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# ON THE ROAD TO OPEN ACCESS: INSIGHTS FROM FRENCH ANTIQUITY JOURNALS AND DATABASES

*In memory of Marie-Christine Hellmann († 2017)*

## 1. Introduction: archaeology, data management and publishing in Nanterre

Through the presentation of antiquity journals and databases conceived or prepared by two academic teams based in the university campus of Nanterre, this paper proposes a glimpse at the current evolution towards open access, as encouraged by the European Union and the French government. Founded in 1969 by René Ginouvès at the young University of Paris Nanterre, with the aim of associating Greek archaeology and information systems in an unprecedented way (http://archaeologicalcomputing.cnr.it/itineraries/institutions/le-centre-taac-et-linformatique-en-larcheologie-classique/), the team "Archéologie du monde grec et systèmes d'information" has not ceased to reaffirm this specificity since then (Fromageot-Laniepce 2019). The team joined ArScAn (http://www.arscan.fr/) at its creation (in 1998) to participate in larger research projects, covering four continents, and a chronological span that goes from prehistory to the beginning of the modern era, on the basis of fieldwork, study of texts and images. It has thus developed digital resources answering the needs of French and international researchers, such as the *Bibliographie de l'architecture grecque* and *Chronique des verres gréco-romains*, which were originally linked to «Revue archéologique», and now need to be sustained as archives.

The Maison Archéologie & Ethnologie project was born in the late 1970s, when Eric de Dampierre set up a department of ethnology and comparative sociology, while René Ginouvès brought together teams of archaeologists interested in questions of methodology. In 1983, the Centre National de la Recherche Scientifique (CNRS) showed its interest in the project and supported the construction of a building on the campus of Nanterre for various teams in archaeology and ethnology from the CNRS, the Universities of Paris 1 Panthéon-Sorbonne and Paris Nanterre. Common services, in particular a scientific publishing service, were created. In 2020 the MSH Mondes succeeded this project in an enlarged perimeter including other fields of the social sciences and humanities. Its editorial unit (Pôle éditorial) gathers staff in charge of the editorial production of several journals in social sciences and humanities, all digitally released and committed towards open access, to varying degrees and according to different models.

Both parties, in a collaborative approach, regularly exchange on the convergence of their practices in the fields of print and digital publishing, interactive media, and the articulation between publications and data, within the framework of research on the digital humanities. This collaboration between the numerous professionals based in Nanterre offers interesting case studies on the evolutions of practices in terms of data management and publication, in a context of Open Science where scholarly publications and data tend to be open more widely and faster. These are some of the developments, encouraged by European and more particularly French institutions, that we want to present here quickly, through examples by our units. We are also interested in similar works from other countries (Fromageot-Laniepce 2019, 139-227; Rossi, Paraciani 2021 for the «Archeologia e Calcolatori»'s recent approach).

## 2. Archaeological journals in the road to open access

The Pôle éditorial of the MSH Mondes is a cluster of a dozen editorial managers from CNRS, in charge of the editorial support and preparation of publications in the Humanities and Social Sciences, mainly journals (https://www.mshmondes.cnrs.fr/revues-pole-editorial). Each staff member is assigned to work for one or two scholarly journals, as part of the support given by the Institute of Humanities and Social Sciences of CNRS to scholarly publishing (Aschehoug 2022). In exchange, these journals are committed towards the development and application of virtuous editorial practices and policies, among which Open Science holds a major, if not a central place. Nine of them are at least partially concerned with archaeology, either Prehistory, Classical or American archaeology (list sorted by founding date): «Revue archéologique» (1844; https://www.cairn-int.info/journal-revue-archeologique.htm?contenu=about), «Journal de la Société des américanistes» (1895; https://journals.openedition.org/jsa/14865), «Bulletin de la Société préhistorique française» (1904; https://www.prehistoire.org/515_p_46628/le-bulletin-de-la-spf.html), «Syria» (1920; https://journals.openedition.org/syria/4125), «Gallia» (1943; https://journals.openedition.org/gallia/268), «Gallia Préhistoire» (1958; https://journals.openedition.org/galliap/268), «Paléorient» (1973; https://journals.openedition.org/paleorient/268), «Archéologie de la France – Informations» (2003; https://journals.openedition.org/adlfi/12592), and «Americae» (2016; https://americae.fr/en/presentation/). This allows us a significant glimpse at different models of periodical publications in archaeology within the context of French academic publishing (Aschehoug *et al.* 2021).

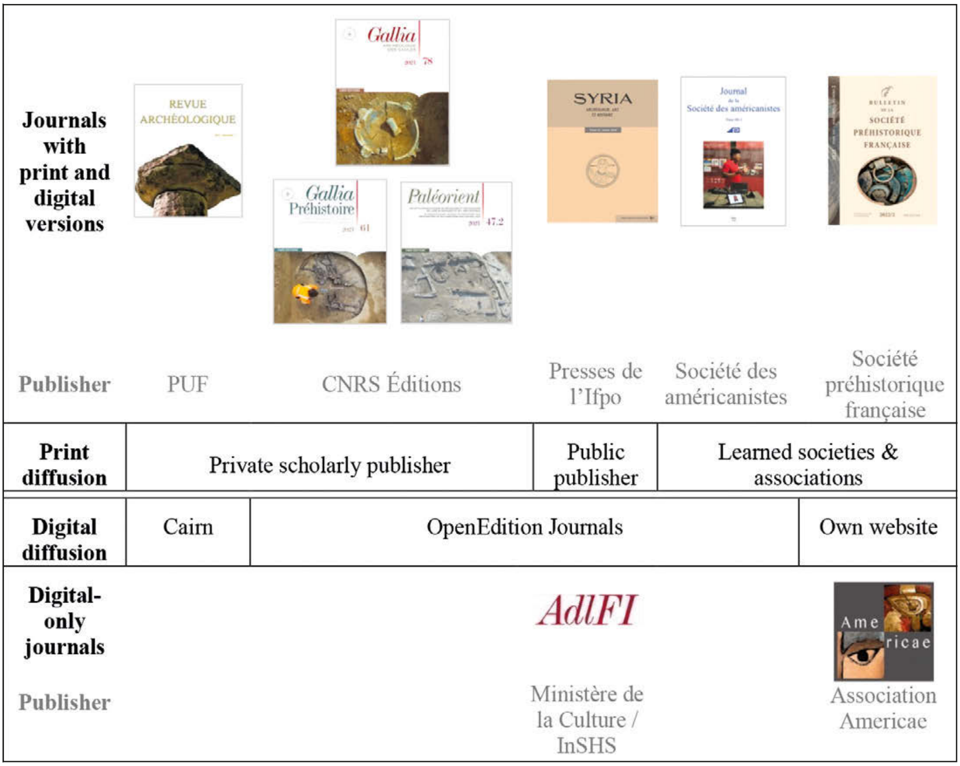


Fig. 1 – The archaeological journals prepared in Nanterre: choices of medium for print and digital diffusion (G. Coqueugniot, CNRS).

While all the journals from the Pôle éditorial are now available online, in a fully digital format, and engaged into the road to open access, they indeed correspond to different economic models, and follow different paths towards Open Science. These differences are partially explained by their different historical background, with creation dates ranging from 1844 to 2016, and an engagement in digital diffusion more or less recent, mostly throughout the 2010s and early 2020s. The journals' histories are linked to a variety of criteria, such as their status, their partnerships with public or private publishers, and their choices in terms of diffusion (Fig. 1).

Among the archaeology journals in the Pôle éditorial, we can find almost the whole range of scholarly journal diffusion possible today, excluding those still exclusively in print, subscription-only journals and preprints journals. This includes journals published by public or private publishers or directly by the learned societies they belong to, available in both print and digital versions or

| Digital libraries | Gallica (until 1951) JSTOR (after 3 y.) | Persée (after 2 y.); JSTOR; Gallica | Persée (before OpenEdition) JSTOR (after 1 to 5 y.) | Persée; JSTOR | not applicable |
|---|---|---|---|---|---|


| Model of digital diffusion | | | Diamond Open Access | |
|---|---|---|---|---|
| | Subscription<br>Open Access after 2 y. | Green Open Access (on HAL)<br>+<br>Subscription | Freemium model<br>- HTML in Open Access<br>- PDF downloads for subscribing institutions | Full Open Access<br>(HTML and PDF) |

Fig. 2 – The archaeological journals prepared in Nanterre: presence in digital libraries and models of digital diffusion (G. Coqueugniot, CNRS).

born-digital journals. The first digital diffusion, usually for the issues predating the 2000s or 2010s, is usually linked to digital libraries such as the French public platforms Persée and Gallica, or the American JSTOR (Fig. 2). More recent issues, with a natively digital, HTML version, are mostly hosted in one of the French scholarly publishing platforms born in the 2000s, such as the public infrastructure OpenEdition Journals (https://journals.openedition.org/6438) or the private academic platform Cairn (https://www.cairn-int.info/about.php), while others still operate independent websites (on the different digital platforms in France, see Anheim, Foraison 2020, 81-88, 239-241).

The archaeological journals of our panel also present a diversity in the degree of openness of their digital version, in correlation with their economic models (Fig. 2). Institutional incentives and requirements have resulted in a steep acceleration in the last decade of the process towards the opening of the journals' contents, although the debate remains open between public and private publishers on the sustainability of the different economic models (Anheim, Foraison 2020, 233-272; Mochon, Vialle 2022). A first step was the reducing of the period of embargo under which journals were only accessed through subscription, from five years in the early 2010s to two years in 2018.

Thus, for example, the «Revue archéologique», although it provides immediate open access to some of its sections (such as the books reviews), is today a journal under a two-years subscription wall on the platform Cairn, while the «Bulletin de la Société préhistorique française» has adopted in 2022 a green open access path – that is the immediate deposit of the preprint version of the articles on the institutional archive HAL-SHS – in parallel to its subscription editor's version. Current European and French governmental policies, followed by CNRS, strongly encourage the so-called diamond open access model, which provides readers with immediate, free access to the edited text (at least in its HTML version) without charging the authors with APC fees (Becerril *et al.* 2021; Bosman *et al.* 2021). This move from print-only to digital open access is illustrated by the journal «Syria», which gained a digital version in 2016, initially with a two-year embargo period, on the publicly-funded platform OpenEdition Journals; this embargo period was then reduced to one year in 2021, and finally abandoned in summer 2022 to adopt the Diamond Freemium model.

## 3. Databases and their association to journals

Two bibliographies, providing a systematic and critical analysis of literature in thematic fields, were published in review articles for almost 30 years in the «Revue archéologique», one of the journals already mentioned above. The articles are freely available in the digital version hosted by the scholarly platform Cairn. Marie-Christine Hellmann, specialist of classical architecture, worked on the *Bulletin analytique de l'architecture du monde grec* from 1991 until 2008, firstly in the research unit Institut de recherche sur l'architecture antique (IRAA), then in ArScAn. She coordinated this publication by collecting over 400 review notes written by 30 experts and published every two years in the «Revue archéologique» (AA.VV. 1992-2008). There is no need to stress the difficulties of this kind of collaboration.

In a similar model, the *Chronique des verres gréco-romains* consists of review articles in the field of Greco-Roman glass. Marie-Dominique Nenna has studied glass and Egyptian faience collections in many museums and she led excavations in Egypt in search of glass workshops (https://ccj.cnrs.fr/spip.php?article2598). She wrote the review articles to draw attention to the development of these studies and to help the specialists of various regions who didn't have easy access to publications (Nenna 2001-2015).

This kind of data sets are not new practices in themselves, but they were rarely included in journals and not easily searchable in their print form, despite several attempts and experiences in the 20th century. Anne-Marie Guimier-Sorbets, professor emerita of Greek archaeology and history of art at the University of Paris Nanterre and a specialist in architecture and architectural decoration, is a specialist of archaeological databases design. In 1980s and 1990s she worked closely with Paola Moscati on the thematic issue of multimedia systems as unitary platforms on which methods and practice of data acquisition, analysis, interpretation, and communication can converge (for an overview, Caravale, Moscati 2021). She proposed the development of web-databases in parallel to the printed bibliographies. The journal's publisher, les Presses universitaires de France, accepted this principle.

The databases were consequently designed and distributed online for almost 15 years, in free access. The *Bibliographie de l'architecture grecque* website includes the notes published in the *Bulletin d'architecture,* and, from 2009, new bibliographical notes exclusively online, while the printed *Bulletin* was replaced by overview articles (Guimier-Sorbets, Fromageot-Laniepce 2006, 19-20; Hellmann 2009-2015). The *Chronique des verres gréco-romains* website reproduces all the reviews published by M.-D. Nenna in her chronicles. Neither thematic articles nor databases were taken over and updated after 2015; each website had thus become an archive.

## 4. Augmented publications and the preservation of digital data

Another example of a database originally intimately linked to a journal appears in the 1980s: the journal «Gallia» initially included a presentation of new data from both planned and rescue excavations in France. This chronicle quickly took the form of a database reproduced first in an annual CD-ROM, and then on the web. It gained its autonomy as the digital-only companion of the journal: «Archéologie de la France – Informations» (Aschehoug, Coqueugniot, Coquet 2021; Coquet *et al.* 2021, 8). In the road towards the increased open access of scientific results, institutions are now encouraging the development of new models of journals, associating additional material previously difficult to include in print, such as 3D models or large sets of research data, often hosted by Huma-Num, a French public research infrastructure with international reach devoted to the Social Sciences and Humanities (https://www.huma-num.fr/about-us/). This has been made easier by the adoption of digital-native editorial processes, which allow a greater interactivity within the journals and in the scholarly world as a whole.

Thus, the transition of the journal «Gallia» towards an "augmented journal" was accelerated by the launch of its digital version in 2018 on OpenEdition Journals and the creation of a companion website in 2020, linking the journal's articles to additional data hosted in Huma-Num servers: inventories, catalogues, etc. (Coquet *et al.* 2021, 9-10). Alongside these new publications, using cutting-edge technologies, the community also has the mission of maintaining past digital resources. The bibliographical web-databases on architecture and glass developed in ArScAn are still hosted on the university

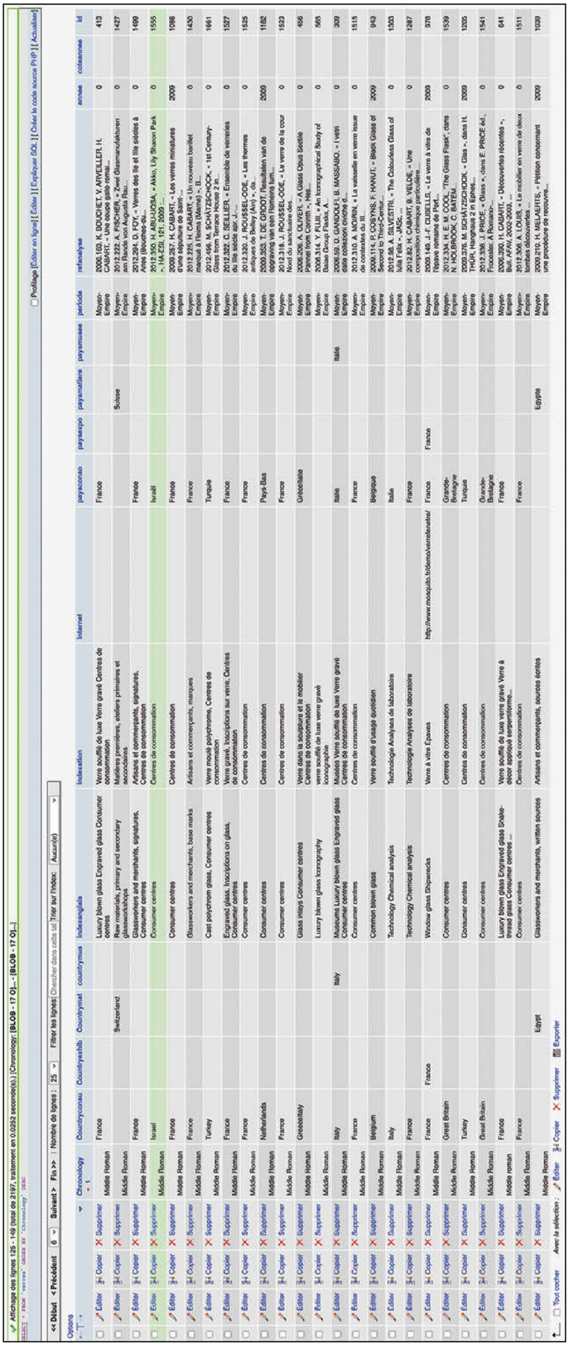

Fig 3 – Screenshot of the *Chronique des verres gréco-romains* database in 2022: a set of records with subject fields in English and French (M.-D. Nenna, V. Fromageot-Laniepce, E. Gimel, CNRS).

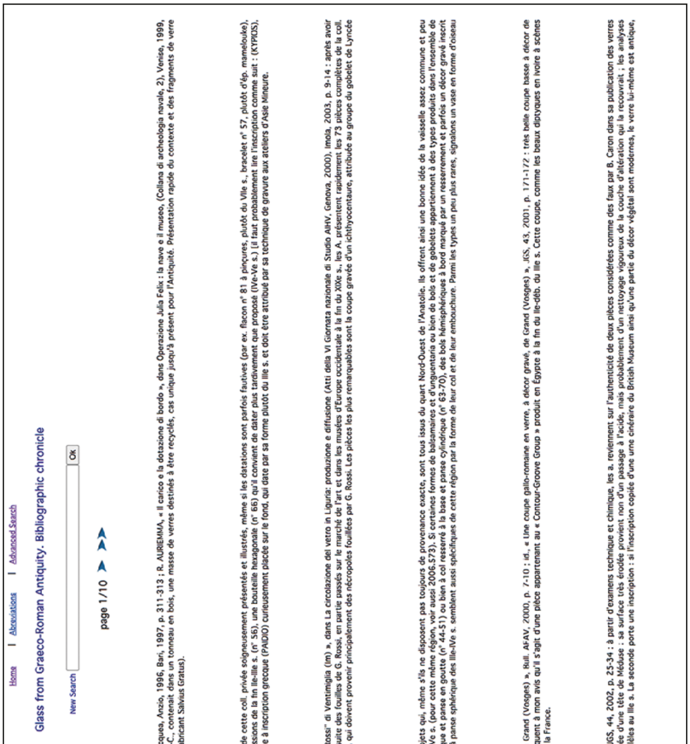


Fig. 4 – Screenshot of the *Chronique des verres gréco*-romains website in 2022: reviews obtained with the searching mode in English (M.-D. Nenna, V. Fromageot-Laniepce, E. Gimel, CNRS).

server of Nanterre with the solution MySQL-PHP initially designed by our colleague Eric Gimel from CNRS. The disappearance of our IT department has forced us to migrate the MySQL-PHP system in Huma-Num servers, after Eric Gimel updated the PHP scripts to ensure its sustainability. This migration has led to a change of url (https://verresantiques.huma-num.fr/) without changing the architecture of the databases (Fig. 3). The user can type in a search form string in French like "coupe" or "bouteille" ("cup" or "bottle") and he gets all the records in the database which are associated with these subject keywords. He can obtain a page of matching results with summaries which are only available in French. The website devoted to glass has a more elaborate search tool that is bilingual on various subject fields, supporting both English and French (Fig. 4). The new website gives the possibility to update the contents.

We are also thinking of a low-tech proposal and a self-archiving practice. We could export all data into a structured text file and make it available with precise metadata and a list of field names, in a repository such as the Huma-Num's platform Nakala, already used by online journals.

## 5. Conclusion

At that time, when the libraries of retired researchers are being donated and integrated into our institutional library, it is important to do the same for the data files. We are engaged in seeking ways to preserve these samples for two reasons: on one hand, the bibliography exists over a long period of time, and on the other hand, that kind of contributions are disappearing from printed journals. In parallel to the transition towards open access, our time is very concerned by a better consideration of the fragility of digital productions on the long-term scale of archaeological research.

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## ABSTRACT

This paper proposes an overview of practices ensuring the gradual transition of printed archaeological journals, already internationalised, to new models of online scientific publishing. It also examines the economic and organisational means that guarantee the sustainability of these models. Our two research units, the Pôle éditorial of the Maison des Sciences de l'Homme Mondes and the team Archéologie du monde grec et systèmes d'information of the ArScAn équipe, are both based in the campus of Nanterre, and collaborative discussions between the numerous professionals based there give us a precious glimpse at the evolutions of practices in terms of data management and publication, in a context of Open Science where scholarly publications and data tend to be open more widely and faster.

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# PEER COMMUNITY IN ARCHAEOLOGY: A COMMUNITY-DRIVEN FREE AND TRANSPARENT SYSTEM FOR PREPRINTS PEER-REVIEWING

## 1. Introduction

The number of scientific articles increases each year since the initiation of scientific journals, with numbers increasing exponentially from the 1980s (Fortunato *et al.* 2018; Fire, Guestrin 2019; Bornmann, Haunschild, Mutz 2021). The current system of scientific publication, mainly managed by a few for-profit publishers that comprise most of the journals worldwide (Larivière, Haustein, Mongeon 2015), has become very costly for our public institutions of research, both financially (Van Noorden 2013; Bosch, Albee, Romaine 2019; Björk 2021; Grossmann, Brembs 2021) and in the time dedicated freely by researchers for peer-review (Kovanis *et al.* 2016; Aczel, Szaszi, Holcombe 2021). This traditional model of publishing in these for-profit journals, limiting dissemination behind paywalls or high publication fees (Siler, Frenken 2019; Kwon 2022), is increasingly being criticised (Tennant 2020; Brembs *et al.* 2021).

As a response to these serious flaws of the academic publication system, academics are increasingly arguing for the adoption of a free publishing process, both for authors and readers, called Diamond (or Platinum) Open Access (Becerril *et al.* 2021; Bosman *et al.* 2021; Pearce 2022). As part of this push for open and freely accessible research, the deposit of preprints in open archives is becoming the norm (Vale 2015; Kaiser 2017; Hettne *et al.* 2021). However, the quality of these preprints must be guaranteed for quality assurance in research (Gunnarsdóttir 2005; Vale 2015; Kaiser 2017) and this is where Peer Community In provides a solution.

## 2. Peer Community In

### 2.1 *Presentation*

In 2016, Peer Community In (PCI), a not-for-profit and non-commercial organization, was created by three French researchers, Denis Bourguet, Benoit Facon, and Thomas Guillemaud, to enable communities of researchers to assess the quality of the work deposited in open archives and thus ensure broad dissemination of high-quality Science (Guillemaud, Facon, Bourguet 2019). After the launch of the pioneering PCI Evolutionary Biology in 2017, PCI Ecology and PCI Paleontology followed in 2018. The organisation presently has 16 different communities in total, including PCI Archaeology which was launched in 2020.

PCI offers an innovative way to evaluate scientific results that are free for authors and readers. The system is based on open peer-review (Ross-Hellauer 2017) and also promotes non-anonymized review – although reviewers can decide to remain anonymous – these two modalities improving transparency, accountability, and constructive criticism (Ross-Hellauer 2017; Besançon *et al.* 2020; Bolek *et al.* 2020; Le Sueur *et al.* 2020). PCI also makes the deposit of all necessary datasets mandatory prior to the recommendation of any preprint and provides the possibility of pre-registration and even registered reports (Chambers 2013; Nosek *et al.* 2018; Ross, Ballsun-Stanton 2021) in a dedicated community created in 2021 to favor reproducibility in scientific research (Munafò *et al.* 2017; Chambers, Tzavella 2022).

This initiative is supported by many institutions including the French Ministry of Research, research organisations like the Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement (INRAE) and the Centre National de la Recherche Scientifique (CNRS), dozens of universities both in France and abroad, learned societies and doctoral schools (see the list at https://peercommunityin.org/pci-network/). It is funded by these institutions and a grant awarded by the French Fond National pour la Science Ouverte (FNSO). In 2020, the PCI initiative was awarded a prize for Library Innovation by the European network of research libraries (LIBER).

### 2.2 *Process*

The process leading to a potential recommendation by any PCI is the same (Fig. 1), except for PCI Registered Reports that have a specific workflow. First, authors deposit their data, code, and preprint on the archiving repository of their choice, one that provides a persistent identifier, mainly DOI. PCI does not maintain any such repository, and preprints can be uploaded to any preprint server, like Zenodo, BioRxiv, OSF Preprints, etc. The second step is for authors to submit their work to the PCI dedicated to their discipline, where they can suggest recommenders among the community. The submission is validated by the managing board, which can also add other suggested recommenders, after an initial check is made on the preprint, the availability of data, code, etc. If a recommender is interested in handling the editorial process over this preprint, they will invite reviewers and handle the complete editorial process as an associate editor in a traditional journal would do. To share the workload and editorial power among recommenders, and to ensure the specialisation of the recommender, every PCI is encouraged to create a pool of recommenders.

At the end of the process, if the manuscript is recommended, the recommender writes a recommendation of the preprint explaining why this manuscript is interesting for the community, and all the editorial process (reviews, answers to reviews, intermediate decisions) is published openly following this text. This recommendation is the publication of PCI and highlights the

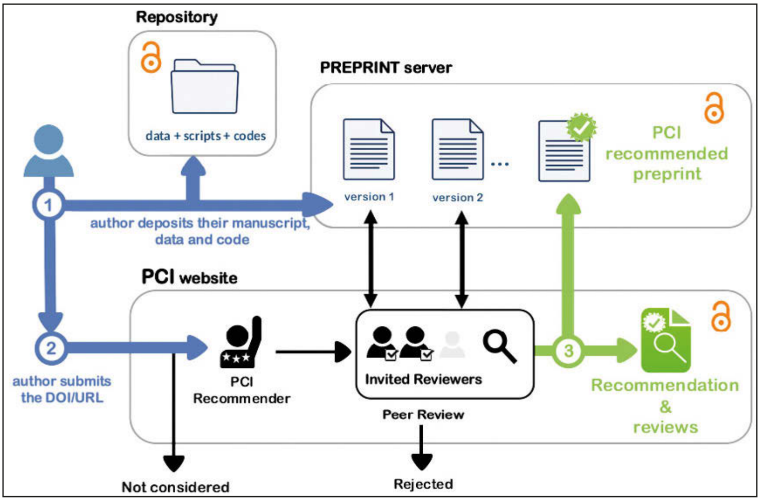


Fig. 1 – Process of submission and evaluation by Peer Community In.

recommender's work. After this recommendation, authors are invited to upload a final version of the preprint on the preprint server using the PCI template. If the manuscript is rejected, at any step of the process, the reviews, answers to reviews, and editorial decisions, are not made public.

This manuscript is still a preprint, even if peer-reviewed and recommended, and can therefore be submitted to a traditional journal if desired or necessary for authors. Most journals accept submission of preprints, and some journals are specifically PCI Friendly. PCI Friendly journals are those who state that they accept submissions of recommended preprints, and can fall in different categories: journals that automatically accept a recommended preprint and publish it without any further peer-review; journals that will give a quick answer to authors as to whether or not the manuscript will go through a new round of peer-review; and journals that accept the peer-review of PCI if they evaluate it as appropriate. Of course, any other journal will have the opportunity to access the reviews to make its own editorial process.

## 3. Peer Community In Archaeology

### 3.1 *Presentation*

Open Science and reproducibility is a topic of current interest for archaeological research (Marwick *et al.* 2017; Karoune, Plomp 2022). Despite the absence of dedicated preprint servers for the topic, and a feebly developed practice of preprints in the community so far, PCI Archaeology was launched

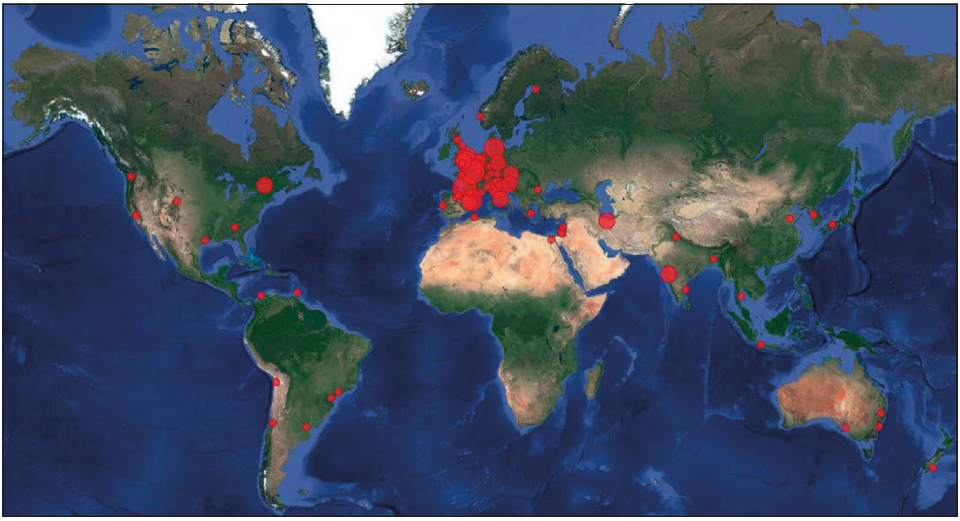

Fig. 2 – Geographic repartition of the recommenders of PCI Archaeology.

in March 2020. More than 100 archaeologists from around the world (Fig. 2) gathered to act as recommenders, covering all fields of the discipline (Fig. 3A, B, and D) ranging from Early Career to Senior researchers in the field (Fig. 3C). Although we have recommenders from many parts of the world, we still have work to do in ensuring a larger representation of recommenders from Global South countries.

### 3.2 *PCI Archaeology in numbers*

From the launch of PCI Archaeology until March 2023, 45 preprints have been submitted for free and transparent peer-review, mostly for Prehistoric periods, and from authors located in Europe, South and North America, Asia, and the Middle East. These preprints were archived by authors mainly in the OSF framework (the generalist OSF Preprints, SocArXiv, EcoEvoArXiv, PaleoArXiv), in Zenodo, BioRxiv, and other servers (Fig. 5). Among these 45 submissions, 43 were taken care of by recommender(s) and sent for peer-review and 2 were desk-rejected (#11 and #23). Among the 43 manuscripts considered for evaluation, 23 were recommended, 6 were rejected or cancelled by authors, and 14 are still in the process of peer review. Finding suitable reviewers for each manuscript has been extremely variable, ranging from sending three to thirty-two invitations to secure at least two reviewers for each manuscript (Fig. 5). Among the 112 reviewers who evaluated the preprints, only 23% decided to remain anonymous. The first round of peer-review took a mean length of

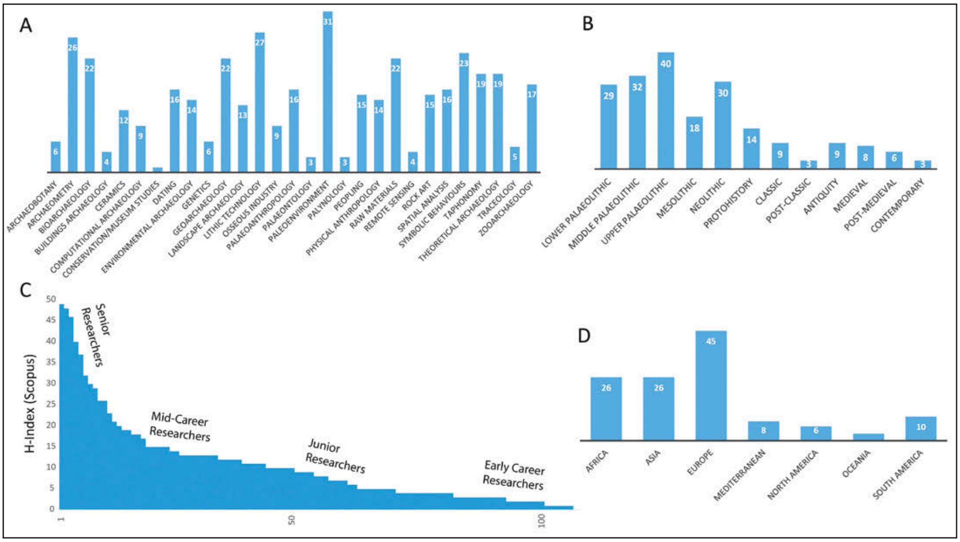


Fig. 3 – PCI Archaeology recommender's thematic (A), chronological (B), and geographical fields of expertise (D). Scopus H-indices used as a proxy of research experience of recommender (C).

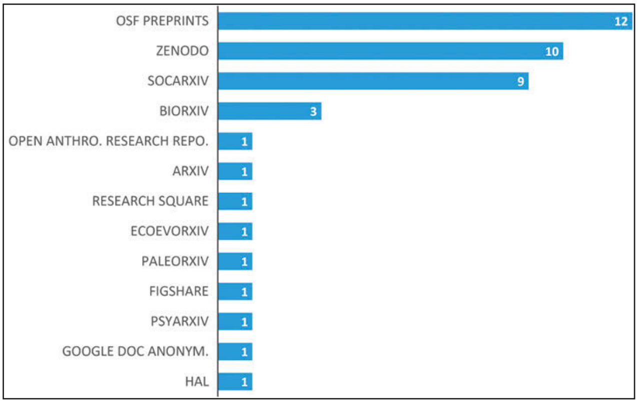


Fig. 4 – Preprint servers used so far for the submissions to PCI Archaeology.

46 days and, including the delay between submission and the invitation of reviewers, and the delay between the last review and the editorial decision, the mean length between submission and the first decision was 52 days.

After the recommendation of the manuscript, most authors decided to submit their work to a journal (Tab. 1). The Peer Community Journal is

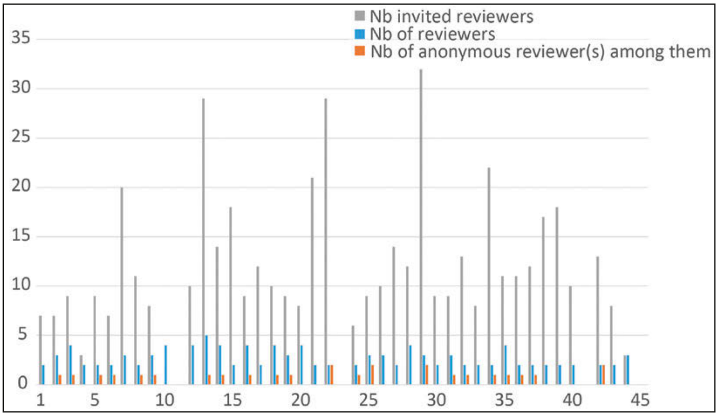


Fig. 5 – Number of reviewers invited, secured, and those who chose to remain anonymous for each submitted preprint.

| Journal | Published as is | Supplementary peer-review |
|---|---|---|
| Peer Community Journal | 11 | |
| PLOS ONE | 1 | 1 |
| Anthropologica et Praehistorica | 1 | |
| Journal of Archaeological Method and Theory | | 1 |
| Journal of Archaeological Science | | 1 |
| Journal of Lithic Studies | 1 | |
| Journal of Open Arch. Data | 1 | |
| Quaternary International | | 1 |
| Quaternary Science Reviews | | 1 |

Tab. 1 – Fate of recommended preprints in journals, whether accepted as is by journals' editors, or sent for a supplementary round of peer-review.

a Diamond Open Acces journal created in 2021. This journal accepts any preprint that has been recommended through any PCI without the need for further peer-review. Authors selected the journal based on the content of their manuscript and the scope of the journal, of course, and some of them endured a supplementary round of peer-review. Journals' editors made this decision based on the reviews published and their knowledge of PCI Archaeology.

## 4. Conclusion

The process of open and free peer-reviewing of preprints through PCI Archaeology introduced in 2020 has been mostly successful. We have attracted more than 100 researchers to act as recommenders and received 45 submissions so far. Although we would be delighted to receive more submissions, we think the use of preprints by archaeologists is still perceived as an atypical publishing strategy in our community. Our data shows that reviewers consider the open process positively although it has been difficult for some manuscripts to secure two reviewers. Reviewers are aware that their free labour will be used here for free open access, instead of providing value to for-profit journals. We consider that good science should be free, peer-reviewed, reproducible, and open access, and that PCI Archaeology offers all those factors. We hope that archaeologists will, in the future, submit their work to our community, accept invited review, endorse the process by citing and considering valuable the recommended preprints as well as spread the word about our initiative.

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## ABSTRACT

The number of scientific articles published each year is on the rise, but the current system, which is dominated by a few for-profit publishers, has become prohibitively expensive for many institutions. This model of publishing is increasingly being criticized for its serious flaws. The deposit of preprints in open archives is a solution for the rapid dissemination of research. However, the quality of these preprints must be ensured. This is where Peer Community In (PCI) comes in, by organizing communities of researchers to assess the quality of the work

deposited in open archives. In 2020, a PCI dedicated to Archaeology was established, with over 100 archaeologists acting as recommenders. These recommenders handle the submitted preprints as associate editors would in traditional journals, but at the end of the process, they write a recommendation text, and the entire editorial process is published with it. So far, PCI Archaeology has received 45 submissions, mostly pertaining to Prehistoric periods, and from authors located in different regions of the world. This open process has been widely accepted by reviewers, but there is still a need to promote the use of preprints in the community of archaeologists.

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# IADI: AN OPEN INTERACTIVE ATLAS OF DIGITAL IMAGES FOR THE JOURNAL «ARCHEOLOGIA E CALCOLATORI»

## 1. Before the Atlas

### 1.1 *The commitment for open visual resources*

Visual resources are fundamental complements for the understanding of scientific literature. In the Arts and Humanities domain, this is especially true as regards material cultural heritage publications, which are – for their very nature – extremely rich in embedded images (photographs, drawings, charts, etc.). In recent years, journals and editorial platforms have put much effort towards improving the fruition experience of their visual contents on the web, offering solutions for the display of static images drawn from publications, and often of the 3D models described therein.

The journal «Archeologia e Calcolatori» (A&C) was founded in 1990 as an international observatory of research in computing and information technologies applied to archaeological studies. The journal's website, established in the mid-1990s for the promotion of its contents, started providing the open access PDF versions of the articles in 2005 (http://www.archcalc.cnr.it/). It also adhered to the Open Archives Initiative and implemented an OAI-PMH repository to provide the articles' descriptive metadata (Barchesi 2019). Soon afterwards, digital versions of the previous print-only issues were also made available on the website, covering the entire production of the journal.

Since the beginning of the online publication of the articles and the open access commitment, the editorial board has paid attention to the enhancement of digital visual contents of the publications besides the textual ones. For instance, as long as colour tables were being printed at the end of each volume, a specific section of the website hosted a digital gallery of the images contained therein (Fig. 1). The implementation of the gallery with new contents naturally stopped as colour images started being embedded into the PDF files of the respective articles since vol. 20 (2009)[1].

Driven by the constant motivation for facilitating interoperability and reusability of materials and data produced, «Archeologia e Calcolatori» recently committed to implementing its digital ecosystem with new cataloguing, navigation, and provision functionalities for the visual resources, to the benefit

[1] For a historical framework of the online provision of contents of traditional vs digitally-born journals in the archaeological domain, see Fromageot-Lanièpce 2019, 160-211. On the solutions adopted by archaeological journals for viewing visual contents, see Rossi, Paraciani 2021, 339-340.

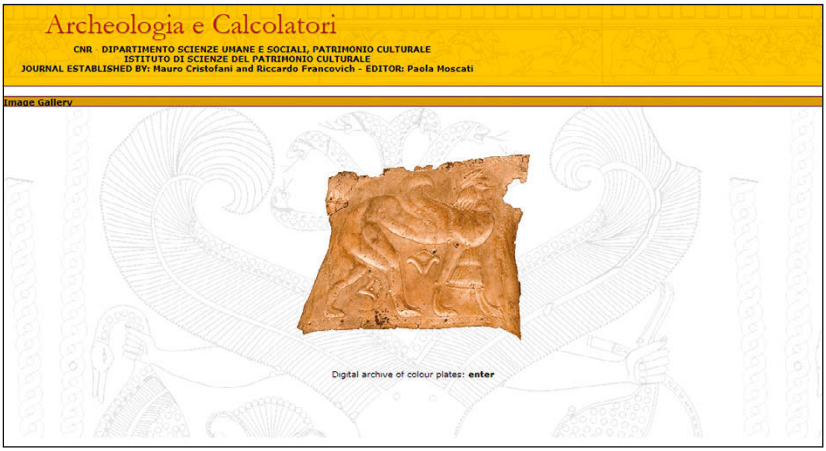


Fig. 1 – Image Gallery access page in A&C website.

of the scientific community interested in the application of IT technologies to archaeology and cultural heritage.

### 1.2 *Integrated access to A&C resources since 2021*

The opportunity of providing full direct access to the images of the publications as standalone resources, aligning «Archeologia e Calcolatori» with the above-mentioned evolving trends in archaeological publishing fruition, recently gained new impulse by the 30th anniversary of the journal (Moscati 2019), with the decision of turning A&C into a content provider for OpenAIRE, which at the time was expanding its scopes beyond the aggregation of literature metadata towards the harvesting of related data archives.

Indeed, after the repository records of A&C textual resources were aligned to the *OpenAIRE Guidelines for Literature Repositories v3* in 2020[2], the journal turned its efforts towards the management of its visual archive. As a consequence, since the publication of vol. 32.1 in 2021, A&C started providing the figures extracted from its articles and any related 3D models as independent resources through the implementation of its custom digital ecosystem (database, website, and repository) (Rossi, Paraciani 2021).

The database model was enriched with specific interrelated entities for the recording of image and 3D model resources, provided with relevant descriptive attributes. The pages of the public website presenting metadata of

[2] This process was described in Rossi, Paraciani 2021. Afterwards, A&C repository records were further aligned to the *OpenAIRE Guidelines for Literature Repository Managers v4* (https://openaire-guidelines-for-literature-repository-managers.readthedocs.io/en/v4.0.0/).

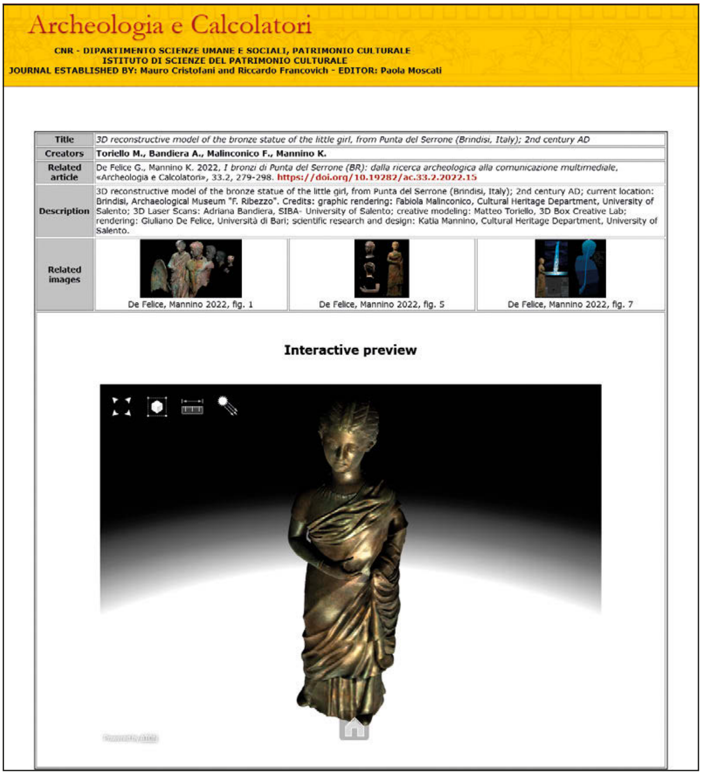


Fig. 2 – A 3D model resource in A&C website, referring to a $2^{nd}$ c. AD bronze statue of a little girl from Punta del Serrone (Brindisi, Italy) from the article De Felice, Mannino 2022 (http://www.archcalc.cnr.it/journal/resource.php?id=model:25).

individual articles drawn from the database were adapted to include links to the web pages displaying each related visual item and its descriptive metadata (e.g., creators, sources, description, licence, etc.), thus creating a net of interlinked textual and non-textual resources. Not only can images and models be viewed in the website[3], but users can also freely download them (Fig. 2). Images and 3D models have been also exposed in A&C's OAI repository as standalone records, in order to enhance interoperability and reuse of such resources. The inclusion of specific metadata elements for the mutual links between image and model records and with the related literature records

[3] For the visualisation of the 3D models, the website was integrated with the open source, web-based software framework ATON 3.0 (https://doi.org/10.5281/zenodo.4618387).

allows maintaining the connection among resources and clearly expressing the semantics of these relations.

The thorough description of the visual resources getting published every year has involved the collaboration of the authors in providing the metadata, especially as regards specific Dublin Core properties such as: "creators", in case visual records are not (or only partially) original creations of the author of the article; potential "sources", when an image is reused from a previous publication; and "rights", as A&C allows to release visual resources with less restrictive licences than the journal's default CC BY NC ND 4.0 International licence. The inclusion of such descriptive metadata ensures full compliance with the *OpenAIRE Guidelines for Data Archives* (https://guidelines.openaire.eu/en/latest/data/index.html) in view of harvesting and aggregation of A&C visual resources by OpenAIRE. Of course, the synergy with the articles' authors is all the more indispensable when it comes to the provision of additional, standalone contents such as 3D models.

## 2. A&C_IADI: an Interactive Atlas of Digital Images

### 2.1 *A legacy through images: 30 years of research in archaeological computing (1990-2020)*

The resources concerned by the work described above currently amount to the ca. 630 images and 25 3D models related to articles of the four journal volumes published since the kick-off of this initiative in 2021 (vols. 31.1, 31.2, 32.1, 32.2). This number will grow as new volumes of «Archeologia e Calcolatori» journal and Supplements will be published. Still, the richness of A&C's archives called for an action of valorisation and sharing of a digital heritage formed by approximately 4000 images spanning the previous thirty-year-long history of the journal (1990-2020). In line with the FAIR principles which have informed the journal's policies through the years, the intent is not only to make those resources available for fruition and reuse, but also to enhance their information potential by annotating them with descriptive metadata.

Therefore, a further initiative has been undertaken to build a new portal presenting 30 years of history of Archaeological Computing through the journal's images: A&C Interactive Atlas of Digital Images (A&C_IADI). The Atlas is one of the projects promoted by «Archeologia e Calcolatori» aimed at enhancing both the multimedia approach – as a dynamic process opposed to a static way of storing and querying documentation and characterised by instantaneity (Orlandi 1999, 3) – and the complex world of computer eidology – which started with the digital representation of the real world (Guidazzoli, Forte 1992) and is now increasingly oriented towards the complex and promising world of virtual reality.

## 2.2 *Preliminary work on data extraction*

To create a new archive of images and metadata of the volumes published between 1990 and 2020, it was necessary to operate at different levels. Information about titles, authors, and volume numbers of the articles were extracted from A&C database, and captions and images were extracted from the source files of the articles. Indeed, we shall recall that A&C is not a digitally-born journal, and has preserved the tradition of producing printed volumes along with the provision of their digital (PDF) versions on its website. The last phases of the editorial work, including the final proofs' correction, are carried out by means of desktop publishing software. Therefore, contrary to digital-only journals which normally provide HTML or XML versions of their publications, no plain or marked-up text files of the final versions of the full articles of A&C were available for past issues to facilitate the extraction and association procedure of figures and captions. This goal was instead achieved by means of a process carried out by A&C's publisher Edizioni All'Insegna del Giglio in Florence, on the paged, print-ready versions of the articles[4].

The publisher was provided with spreadsheets containing the articles' data which had been retrieved from A&C database, to be implemented with information on images and captions. After converting A&C volumes' files to the latest version of Adobe InDesign, the publisher isolated the captions in the files of each volume by filtering the paragraph styles, and removed segmentations of their texts over multiple lines. A list of unique names of the JPG images contained in exported PDF files was generated as a plain text file, which could then be imported into the spreadsheet, one row per filename. A similar process was adopted to extract all the captions, save them to a plain text file – one row per caption – and then import them into the spreadsheet. This ensured that each row in the spreadsheet had the proper relation between image filenames and captions, and that these were associated with the related article. The workflow applied to the very first issues of the journal differs in that the source files consisted in the digitised versions of the printed articles, which required an OCR conversion of the PDF files into editable text files.

Data retrieved were then imported into the dedicated database table of the new web tool developed for the public presentation of A&C 1990-2020's visual contents.

## 2.3 *Database implementation*

A&C's Interactive Atlas of Digital Images was conceived as a standalone application with respect to the journal's website, although it accesses the same

[4] We wish to thank Tommaso Ariani, head of the publishing house, for sharing with us the procedure he followed for the retrieval and extraction of data from the original source files of the articles, which implied a careful work on "legacy resources".

underlying database. Since the application is a static archive of the first 30 years of journal publications, the database state is "locked", meaning that it is read-only. We then defined and implemented the database table structure that would hold all Atlas images. Each row in the table represents an image, which is defined by the following main attributes:

– Caption
– Filename
– Figure number
– Article the image belongs to.

The filename simply points to the physical image file in JPEG format, stored on the same server as the web application. The article the image belongs to is identified by a set of specific attributes that are all part of the same table, including its title, the order it appears in the respective volume, and the volume number and type.

It was also necessary to add an attribute holding the actual numeric identifier of the article as found in the DB, to facilitate some queries used by the web application. This task was accomplished by means of a custom command line interface (CLI) tool, which is versioned along with the web application and exposes a few additional commands to manipulate the database table. Indeed, the application does not rely on a migration system such as those found in many modern web frameworks, at least for the time being, considering the simplicity of the underlying structure. The fact that references to foreign tables are minimal reduces the number of joins required to perform "SELECT" queries on it.

### 2.4 *Web application*

The main web application is written using PHP 8.1 as server-side language, with plans to include features from the recently released 8.2 version (December 2022). Specifically, it implements the widely used Model-View-Controller (MVC) design pattern (Leff, Rayfield 2001) by leveraging individual Symfony components (https://symfony.com/doc) and adopting an Object-Oriented Programming (OOP) style. The reason for choosing PHP as server-side language is twofold: i) previous experience in working with it; ii) possibility to reuse parts of the code for the new version of A&C website, which is currently running in a PHP hosting environment. The frontend is implemented with native rendered views (via the Plates library; https://platesphp.com), with additional client-side JavaScript for some parts – especially those generating content from AJAX calls. In terms of stylesheets, the Atlas relies on the open source minimal CSS library Spectre.css (https://picturepan2.github.io/spectre/), mainly for the basic layout and to ease the implementation of responsive features.


Fig. 3 – A&C_IADI: application's home page, providing access to journal and Supplements' volumes.


Fig. 4 – A&C_IADI: image browsing by a volume's articles, listed by their publication order. The full title of the article is displayed by hovering with the mouse over its card (detail of Limoncelli, Scardozzi 2013 in A&C 24).


Fig. 5 – A&C_IADI: browsing by an article's images (above) and image slideshow with captions visualised on a desktop screen (below). The example refers to Fig. 2 in Limoncelli, Scardozzi 2013, showing some virtually reconstructed monuments of Hierapolis (Phrygia).

The application has a simple structure, in terms of navigation. The home page (Fig. 3) shows card-like buttons in order to browse images by volume (grouped into journal and Supplements issues), while the main navigation bar includes links to the "About" page and the search feature, which is still under implementation. Navigating back and forth between views is facilitated by breadcrumbs on all pages. Clicking on a volume opens a view listing all the articles published in that specific volume. The image representing each article card is selected randomly by the system from the set of figures related to the article itself (it can vary with each request). Articles are identified by their publication order within the volume and by the short citation. Hovering with the mouse over an article card shows the article's full title (Fig. 4).

After selecting an article, a gallery view opens with all its figures and truncated captions. Clicking on any figure in the gallery opens a slideshow of all images with full captions, implemented with the open source JavaScript library Spotlight.js (https://nextapps-de.github.io/spotlight/) (Fig. 5). At the bottom of the image gallery in the article view the full article citation – formatted according to the journal's style – is included. There is also a "Read article" button that opens the article's page in A&C's website in a new browser tab. A search feature provides the user with the possibility to search for keywords in image captions, which often include terms related to the images' subjects, in addition to filtering by other metadata (e.g., publication year, article title and authors etc.).

## 3. Future perspectives

In view of enriching the search feature with filters for image categories (cf. https://idai.world/what/images; https://arachne.dainst.org/), terms extracted programmatically from image captions could be used to generate labels for the automated classification of image topics, to provide granular filters for specific searches. We are considering Machine Learning (ML) frameworks and tools for image classification, with a preference for open source software, such as, e.g., the Python framework TensorFlow (Seetala, Birdsong, Reddy 2019) that we started using for some preliminary tests. Similar experiences in archaeology or adjacent fields will be evaluated, possibly to reuse any open existing, pre-trained classification models. The data generated by this classification effort, as well as the already available information associated with the images, could be made interoperable by exposing a dedicated REST API that external services and providers could query automatically to retrieve the data in a structured format (e.g. JSON).

The provision of open visual resources from A&C's website and from the Atlas to Europeana (https://pro.europeana.eu/), by implementing respective repositories with the Europeana Data Model (EDM) format, is also being considered to further increase dissemination and reuse opportunities. This would augment A&C's presence in the Europeana Archaeology collection, currently consisting of more than 900 literature resources (articles) from both the journal and the Supplements (Piergrossi, Rossi 2019).

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## ABSTRACT

Scientific literature understanding benefits from visual resources, which is even more evident in the case of material cultural heritage. In recent years, journals and publishing platforms have been increasingly offering extensive access to publications via the contextual provision of visual media, such as images and 3D models. The diamond open access journal 'Archeologia e Calcolatori', founded in 1990, started publishing its articles in 2005 on its website and has always paid attention to giving proper value and presentation to visual contents related to publications. Indeed, it maintained an online image gallery displaying colour plates from volumes until coloured images started being embedded in the articles' PDFs (since 2009). Then, in 2021, the journal added images and 3D models as resources together with publications and displayed them both as standalone content and in relation to articles. However, this later work did not include the previous thirty-year-long history of the journal, since it required close cooperation with authors. Thus a new dedicated web application was specifically developed to present a structured and visually appealing archive of about 4000 images. The paper illustrates this application, entitled A&C_IADI (Interactive Atlas of Digital Images).

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# SHARING STRUCTURED ARCHAEOLOGICAL 3D DATA: OPEN SOURCE TOOLS FOR ARTIFICIAL INTELLIGENCE APPLICATIONS AND COLLABORATIVE FRAMEWORKS

## 1. Introduction

This paper presents the W.A.L.(L) Project, funded by CNR-ISPC (Institute of Heritage Science) (2020-2021). It is aimed to apply quantitative analysis methods and Machine Learning to ancient architecture and to create a dedicated research infrastructure based on an open source technology, according to principles of Open Science.

The Project, carried out by an international and multidisciplinary research group[1], was mainly inspired by the unexpected results of the 2015-2018 excavation campaigns in the North-Eastern Sector and in the Southern Area of the Phaistos Palace, where an Early Iron Age architectural phase was identified. Indeed, until recent years, the Early Iron Age of Phaistos deserved little attention, since the interest of excavators and scholars focused on the palatial phases of the 2nd millennium B.C. and, to a lesser extent, on the Hellenistic period (La Rosa 2010). During the project, a training dataset has been created, consisting of about 1300 digital 3D models of stones, belonging to twelve walls dating from the Late Minoan IIIC (1200-1050 B.C.) to the Geometric Period (8th century) and located in four archaeological sites in Crete (Phaistos, Ayia Triada, Sissi, Anavlochos). The aim of the project was to query the 3D digital data and to extract numeric features significant for the archaeologists, in order to:

– identify building practices (working and setting up of the stones) on a statistical base;
– evaluate continuity/change in practices, due to: *habitus*, tradition, groups identity, chronology;
– contribute to the definition of an intra-site relative chronology of the walls;
– identify restoration patterns.

F.B.

[1] P.I.: Dr. Francesca Buscemi (CNR-ISPC), Classical archaeologist and topographer; Partner Coordinator: Prof. Jan Driessen (Université Catholique de Louvain), Aegean archaeologist; partners: Prof. Maud Devolder (Ghent University), Aegean archaeologist; Dr. Marianna Figuera (University of Catania), Aegean archaeologist; Prof. Florence Gaignerot-Driessen (University of Cincinnati), Aegean archaeologist; Prof. Giovanni Gallo (University of Catania), mathematician and computer scientist; Dr. Angelica Lo Duca (ISPC-IIT), computer scientist; Dr. Andrea Marchetti (ISPC-IIT), computer scientist.

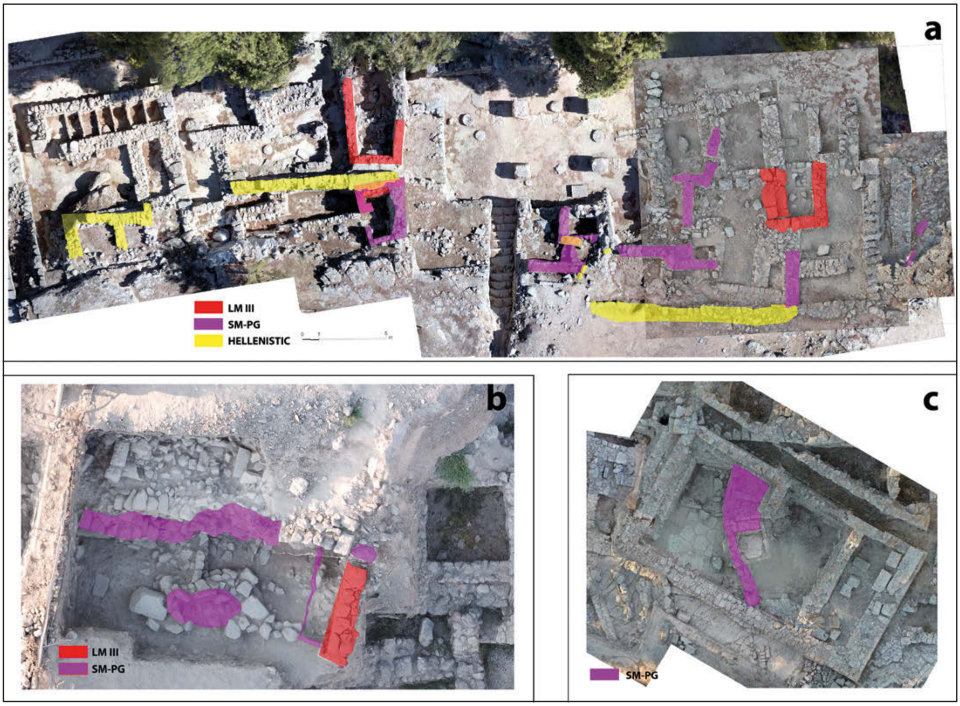



Fig. 1 – Phaistos, Post Minoan phases after the recent excavations by the University of Catania: a) NE Sector (2015-2018); b) Room NN (2022); c) so-called Temple of Rhea (2017) (orthophotos by F. Buscemi, M. Figuera, M. Spiridakis).

## 2. Geometrical data processing and information extraction

The 3D wall photogrammetric models were processed in two steps:

– "segmentation" of each model into a collection of meshes relative to the visible part of a stone in a wall (wall face). These meshes are referred in the following as "stone faces";

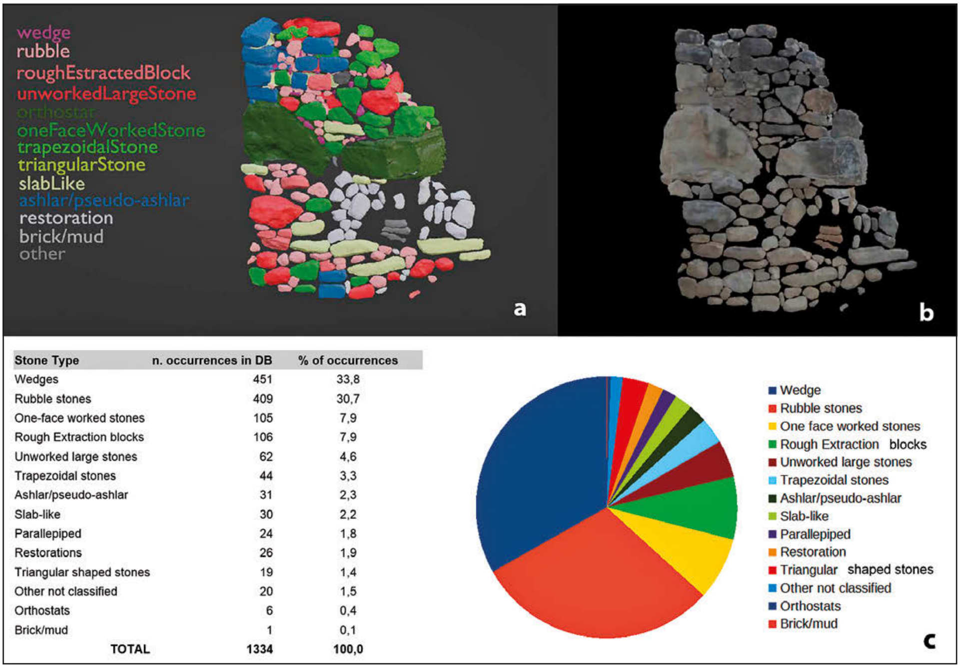
– "computation" of numerical information about position, orientation, shape, neighboring relations between stones.

The output of the "segmentation step" is a collection of files each one representing a wall facing stone in wavefront OBJ format. The resulting objects are stored in a hierarchical folder system to allow stone retrieval and visualization with any 3D software able to read OBJ files. The output of the "computation step" is a table of numerical values stored in a CSV format. The table reports several numerical values obtained by applying geometry processing analysis algorithms to the stone faces.

## 2.1 *Segmentation. Stone faces extraction and classification*

Stone walls segmentation is an important issue in the field of cultural heritage studies (Valero, Bosché, Forster 2018; Murtiyoso, Grussenmeyer 2019; Koubouratou *et al.* 2021; Pavoni *et al.* 2022). Most of the published approaches require projecting the 3D structure onto a plane: to delineate the contour of the stones hence becomes an image processing task. Once the planar contour has been found, it can be back-projected on the 3D model to guide a segmentation process. Unfortunately, this approach requires the choice of a suitable projection plane and some degree of regular repetition in the stone layout. However, it is difficult to apply in a reliable way to the complex layered and highly irregular Prehistoric/Protohistoric walls. This has forced a manual processing of the models (Fig. 2a-b).

A suitable operative environment to perform this task has been identified with open source software Blender 3D which supports visualization, editing and information extraction from 3D meshes in a unified environment. The rich Python API (bpy libraries) allows direct data processing with scripts




| Stone Type | n. occurrences in DB | % of occurrences |
|---|---|---|
| Wedges | 451 | 33,8 |
| Rubble stones | 409 | 30,7 |
| One-face worked stones | 105 | 7,9 |
| Rough Extraction blocks | 106 | 7,9 |
| Unworked large stones | 62 | 4,6 |
| Trapezoidal stones | 44 | 3,3 |
| Ashlar/pseudo-ashlar | 31 | 2,3 |
| Slab-like | 30 | 2,2 |
| Parallepiped | 24 | 1,8 |
| Restorations | 26 | 1,9 |
| Triangular shaped stones | 19 | 1,4 |
| Other not classified | 20 | 1,5 |
| Orthostats | 6 | 0,4 |
| Brick/mud | 1 | 0,1 |
| TOTAL | 1334 | 100,0 |

Fig. 2 – a) False color rendering of the stones according to their semantic classification; b) segmentation of the wall into wall facing stones; c) pie chart of the occurrence of the stone types within the sample walls.

developed in Python language. It also permits the easy development and integration of specialized tools within the Blender system as an "add-on" to its standard version. So, each wall has been manually segmented and classified to obtain a collection of 3D models of the wall facing stones. The segmentation procedure has been carried out as follows: the whole 3D mesh of each wall unit has been partitioned into disjoint "vertex groups". Each of these groups contains the portion of the mesh relative to the visible part of a stone in the wall (wall facing stones). During segmentation, each vertex group has been assigned a semantic category, according to the logical model and the vocabulary developed within the project (Fig. 2c). As a side benefit from the segmentation and classification process it is easy, within Blender, to obtain false color representation that can be helpful to recognize and visualize stone types distribution and localization in a wall (Fig. 2a-b).

Senior archeologists and students both in archaeology and computer science have carried out the segmentation process and the results have been carefully double-checked in order to assure that the extracted meshes where both geometrically and semantically consistent and appropriately classified. Inter-operator variability in performing the segmentation process has been considered in designing the study: evaluation tests have been conducted to estimate the impact of the inter-operator variability factor during this stage of data processing. The tests consisted in assigning the same models to two students of the BA course of Computer Science at the University of Catania and asking them to carry out the segmentation after a brief training. The set of vertices assigned by the two independent operators to each stone have been hence compared and, on the average, only 11% of the vertices were assigned to different groups. The observed discrepancy has only a millimeter impact on the numeric properties of the stones.

The segmentation step is completed with the extraction of the vertex groups as separate "Blender objects" (i.e., separated mesh) and organized in a hierarchic collection tree. In turn, the "Blender objects" have been saved as independent files in wavefront OBJ format. The collection of all the files has been stored in an organized folder system to allow easy retrieval by a relational DB for further visualization, statistical computation, geometry processing and Machine Learning tasks.

### 2.2 *Computation of numerical attributes of the stones*

In order to carry out quantitative analysis and to apply Machine Learning methods to the study of the walls, the raw geometric data (i.e., the meshes and the textures extracted from the whole model of the wall in the previous step) is used to compute a plethora of numerical attributes related to the shape, location and orientation of the stones. Using a Python script that relies on the open source Python library Trimesh (https://trimsh.org/), several indices may be easily computed. For each stone they include: statistics about vertices, edges and triangles in the mesh representing the stone, coordinates of the geometrical center of the stone face, dimensions of the bounding box of the stone aligned with the reference system, dimension and orientation of the minimal bounding box of the stone, mean directions and variances of the normal to the triangles that form the mesh of the stone, number of touching (or very close) stones. Other indices related to the stone face shape are also computed: sphericity, planarity, flakiness, mean discrete gaussian curvature, etc.

All the computed quantitative data are compiled in a CSV allowing data analysis by using traditional statistical analysis and Machine Learning algorithms to attempt automatic classification, hypothesis validation and automatic knowledge discovery. These numerical data are as well stored as attributes of the "stone" entities into the relational database, allowing the user to ask queries based on them. Machine Learning attempts to imitate the human expert classification of the stone into their archeological type have been carried out with some promising results. In particular it has been possible to train a "random forest classifier" (Breiman 2001) (a randomized generalization of decision trees, Breiman 1984) to automatically discriminate between "rubble stones" (unworked stone used as building materials), versus "wedges" (saturating interstices between bigger stones) achieving an accuracy of 83%. Furthermore, by using recent results in explainable Artificial Intelligence (Ribeiro, Singh, Guestrin 2016; Lundberg, Lee 2017), it has been possible to verify that some features that are intuitively adopted by a human expert to assess stone type like: size, number of touching or almost touching stones, flakiness, etc., have indeed relevance also for the automatic classification algorithms.

G.G.

## 3. The DB design

The management of the data related to the 3D models has been done through the design of a specific DB. The first aspect that has been stressed was a correct data conceptualization and semantic classification: a long time was dedicated to this step, extremely thorny because of its importance (Manferdini *et al.* 2008; Noardo 2016). Because of the lack of DBs specifically addressed to ancient architectural data, it was necessary to choose as main reference the CIDOC-CRM and its extension CRMba (Ronzino *et al.* 2015), devoted to archaeological monuments. Its current version (1.4, December 2016) proposes 5 classes ("Built Work", "Morphological Building Section", "Filled Morphological Building Section", "Empty Morphological Building Section", "Stratigraphic Building Unit") and 8 properties for the specific "Buildings Archaeology Model", linked to others CIDOC-CRM classes (as

"Event", "Activity", "Production", "Time-Span", "Place", "Type", etc.) and properties, some of them referred to the "Excavation Model" ("Excavation Model Classes", "Stratigraphic Interface", "Stratigraphic Unit", etc.). The AAT - Art and Architecture Thesaurus of the Getty Institute (https://www.getty.edu/research/tools/vocabularies/aat/) was the reference vocabulary used to normalize the terminology.

Starting from these requirements, a system has been created to manage and query all the information, in order to apply a complete classification of the stones and masonry types. The entities "Wall facing elements" and "Masonries" are the core of Entity-Relationship Diagram (Fig. 3a). Linked to them there are many other entities, which are possible to gather in four groups: 1) localization entities; 2) chronology entity; 3) typology or characteristic entities; 4) documentation entities. The logical model, developed from the ER Diagram, describes in detail all the entities, which are the DB tables, with their attributes and relationships. It was developed considering first of all the 3D data managed into the "Wall facing elements" table, which includes all the quantitative data exportable from Blender in CSV format and descriptive information relating to the wall facing stones, in other words every single stone element of the exposed wall. The "Masonries" table collects all the descriptive information relating to each single wall, including its archaeological interpretation. Every wall is also identified through the localization in the archaeological site, excavation area, quarter, or room, etc. as through the geographic coordinates (GPS).

The information about localization is collected into three tables. "Finding areas", where the sites involved in the project and information about the areas of discovery are collected; "Stratigraphic units", referring both to the US (soil deposits) and the UM (masonry stratigraphic units), which chronology can be here indicated; "Stratigraphic relations", where it is possible to define the stratigraphic relationships existing between the walls and the stratigraphic units; and "Activities", to be populated with the information relating to survey activities, archaeological excavations, etc. that have affected an area or a single wall. The chronology is managed into the "Periods" table. All the characteristics and typologies are managed into seven tables: "Dimensions"; "Materials"; "Functions" (foundation, elevation, etc.); "Masonry types"; "Stone types"; "Working traces" and "Petrography". Finally, all the data coming from previous documentation are collected into the tables "Visual items" and "Documents".

The last aspect that has been stressed is the accessibility, according to the FAIR principles (Wilkinson *et al.* 2016), guaranteed by well-defined protocols about user types, roles, and permissions. In fact the system is intended to be used by multiple users with different admission rights.

M.F.

## 4. The DB construction

Within the W.A.L.(L) Project, a prototype of a web application has been implemented based on the Django framework (https://www.djangoproject.com/). The prototype manages manual data entry to the W.A.L.(L) database, which implements the defined ER schema.

### 4.1 *The implemented prototype*

The Django framework is a free and open source web application framework written in Python, widely used in archaeology (Fazal 2009; Gallo, Roberto 2012; Gambaro, Costa 2016). The architecture of the proposed prototype (Fig. 3b) is organized into the following components:

– the Django framework that acts as an orchestrator among the different modules;
– a database that implements the ER schema of the project. The original ER schema written using a spreadsheet is automatically mapped to Django through custom software;
– a data entry module for the manual insertion of new entities in the database, respecting the defined schema, with the related constraints;
– an automatic CSV importer, which imports data exported directly by Blender;
– a web interface, enabling users to access and query the resources contained in the database.

Different roles could be created to manage access to the resources. Now, role management has not been implemented in the platform, but an authentication mechanism is envisaged. From an Open Science perspective, at least basic access to resources should be guaranteed to all users, including non-registered ones. This basic access could involve consulting the name and description of each entity. Then, based on the role of the user, different details could be provided for each entity contained in the database. The Django framework also provides a user interface. The data entry module (Fig. 3c) currently foresees the manual insertion of some properties of the wall facing elements.

A.L.D., A.M.

## 5. Expecting results related to archaeological open issues

The W.A.L.(L) Project is still ongoing, and we are currently engaged in DB population and in the query construction. Machine Learning and the query about the use of building materials according to their relative chronology, typology, shape, working degree, position within each wall, dimension and occurrence can contribute to use ancient architecture as a cultural-related

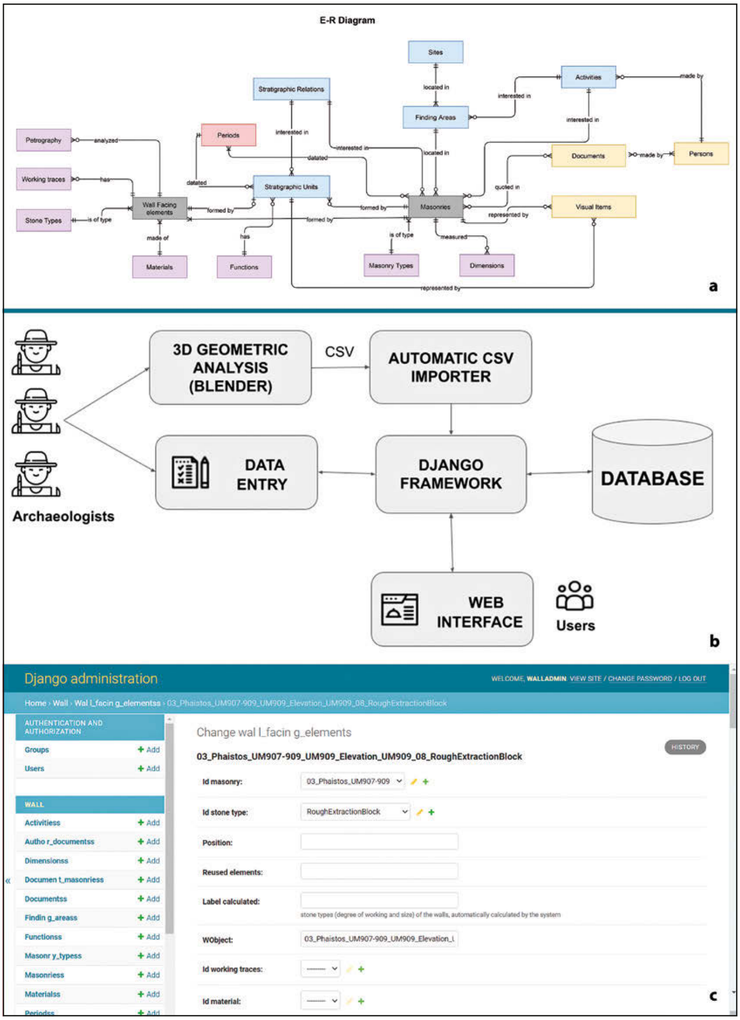



Fig. 3 – a) The Entity-Relationship Diagram with entities fulcrum of the system (gray) and entities related to localization (light blue), chronology (red), typology or characteristic (violet), documentation (yellow); b) the prototype architecture of the web application; c) the data entry model.

tool in order to answer some historical and archaeological questions. One of these can be the difference among different areas of Crete in the adoption of certain building materials, also with reference to their availability, as an architectural variance of the notion of determinism introduced by the Processual archaeology: see, for example, the southern sites in the Messara (Ayia Triada

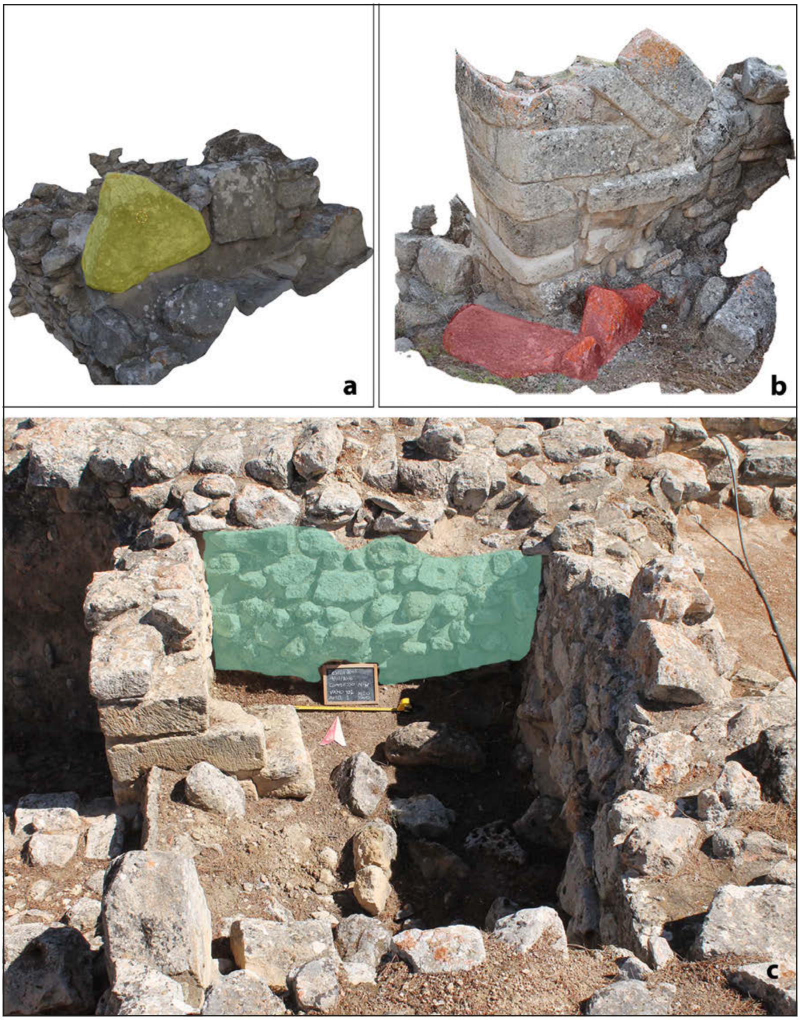



Fig. 4 – Guide fossils of the Geometric architecture at Phaistos: a) NE Sector, Room 103, Wall 907, triangular shaped stone used as a socle; b) Geometric Quarter, Room AA, polygonal slabs vertically arranged, modifying a previous wall line; c) NE Sector, Room 102L, lining wall.

and Phaistos), in comparison with northern ones, Sissi and Anavlochos, this last an impervious and difficult to supply place.

Another question can relate to the currently widely discussed topic of the transition between Subminoan, Protogeometric and Geometric in Crete, that is the existence or the degree of a rupture in architectural tradition after the

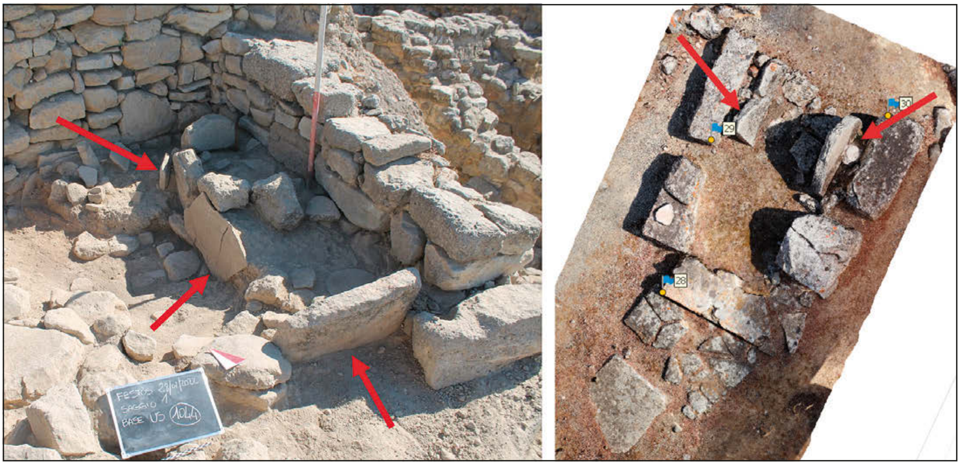



Fig. 5 – Polygonal slabs vertically arranged: a) Phaistos, Room NN; b) Ayia Triada, Altar.

LMIIIC period (12th-early 11th century). As far as Phaistos and Ayia Triada are concerned, some details seem to speak about a continuity. We can mention, for example, the treatment of the jambs, with a pseudoashlar arranged alternatively by headers and stretchers: it is already in use in LMIIIC in Phaistos and seems to have continued in the walls of the Protogeometric (9th century); the same consideration is valid for the rough coursing of the wall faces.

On the contrary, some examples of the 11th and 10th century present some features not seen before, which we propose to consider like guide fossils: the polygonal or triangular shaped orthostats (Fig. 4a) often constituting a socle in the wall; the lining walls built against previous structures, sometimes modifying their line and shape (Fig. 4c); the polygonal slabs vertically arranged, again used in order to modify earlier structures (Figs. 4b, 5) (hearths and even altars); the reuse of building material by such a poor architecture exploiting all the available structures and materials.

Following these considerations, we can assume as a working hypothesis an evolution from LMIIIC (12th-11th century) more squared stones to a crisis of the regular masonry typology in the SM/PG (11th-10th century), until a new interest for regular wall facing in the 9th century (PG).

The work until now developed within the W.A.L.(L) Project definitively stimulated such proposals, in particular through some steps of the workflow: the very detailed computer processing of the virtual 3D models of the walls; the long discussion between the partners about the architectural vocabulary and the building materials for the setup of the Logical Model; the construction of the query for the DB; the trials of ML and data mining process in order to identify relevant features for the archaeologists. We hope that our work will demonstrate how the use of Artificial Intelligence can provide a numeric base for archaeological interpretations in the challenging field of the poorly predictive Prehistoric/Protohistoric and not monumental architecture.

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## ABSTRACT

This paper focuses on collaborative methods and open source tools aimed to analyze and query 3D photogrammetric models of ancient architectures. The processing of virtual models led to the constitution of a training dataset of around 1300 wall facing stones from four archaeological sites in Crete. Through a purposely-conceived add-on of the open source software Blender, some algorithms expressed in Python are able to extract archaeologically significant features and to perform processes of Machine Learning and data mining. The resulting data are imported into a dedicated DB managed through a web application based on the open source framework Django. This workflow addresses some peculiar challenges of the application of Artificial Intelligence to archaeological heritage: the lack of training dataset, particularly related to architecture; the lack of best practices for geometry processing and analysis of 3D data; the use of poorly predictive data in semi-automatic processes; the sharing of data into the scientific community; the importance of the open source technology and open data.

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# CHALLENGES IN RESEARCH COMMUNITY BUILDING: INTEGRATING TERRA SIGILLATA (SAMIAN) RESEARCH INTO THE WIKIDATA COMMUNITY

## 1. Introduction

Community building creates a network. This also applies to data which may result in a knowledge graph. In the case of graph-based models, nodes and edges can be modelled in the Resource Description Framework (RDF) standard based on a semantic network as Linked Open Data (LOD) being a part of the Semantic Web. In the RDF model, each statement consists of the three units subject, predicate and object, whereby a resource as a subject is described in more detail by another resource or a value (literal) as an object. With another resource as a predicate, these three units form a triple ("3-tuple"):

(Subject) -[Predicate]-> (Object)

As an example, the ancient Greek philosopher Plato is a human entity, that can be described in RDF using common, well-known Semantic Web vocabularies and ontologies, especially the RDF Schema (Brickley, Guha 2014) and the Friend of a Friend (FOAF) vocabulary (Brickley, Miller 2004):

(ex:Plato) -[rdf:type]-> (foaf:Person)

The four LOD principles (Berners-Lee 2006) should be applied to domain-specific archaeological data to create an Archaeological LOD Cloud as part of the Giant Global Graph, the Linked Open Data Cloud (more about LOD in archaeology can be studied by Isaksen 2011; Thiery 2013; Schmidt *et al.* 2022). One possibility to create a direct link into the LOD Cloud and integrate volunteers and citizen scientists is Wikidata (Vrandečić, Krötzsch 2014). Wikidata is a free and open knowledge base, a secondary database as well as a data hub where everybody can add and edit new entities and classes. Wikidata is the central storage for structured data of projects by the Wikimedia Foundation, such as Wikipedia and Wikimedia Commons. Data in Wikidata is available under a free licence (CC 0), multilingual, accessible to humans and machines (GUI, API, SPARQL), exportable using standard formats (JSON, RDF, XML) and interlinked to other open data sets in the LOD Cloud. The English author and screenwriter Douglas Adams, best known for *The Hitchhiker's Guide to the Galaxy* where "42" is the answer to the ultimate question of life, the universe, and everything, can be described in Wikidata as:

(wd:Q42) -[wdt:P31]-> (wd:5)

This means Wikidata Entity Douglas Adams (Q42, English science fiction writer and humorist) is an instance of (P31, a particular example and member) a human (Q5, the common name of *homo sapiens*). Q42 is commonly used to describe the Wikidata data model (Fig. 1). Wikidata's data model consists of identifiers, labels, descriptions, and aliases, as well as statements such as properties, values, qualifiers, and references. E.g., Plato is described with the identifier Q859 as an instance of human, with male gender, with classical Athens citizenship, date of birth 347 BCE (Gregorian), working in the fields of philosophy, literature and politics.

Wikidata properties and items suffice for a large range of Roman ceramics data, reflecting a diverse and active community of users but also diverse implementations of data models. We would like to discuss the benefits and challenges of integrating communities. The Leibniz-Zentrum für Archäologie, Mainz (LEIZA) curates the Samian Research database, a treasure-house of economic data on Roman trade and the Terra Sigillata (Samian Ware) industry. Over six decades, a broad European user community of established research institutions, citizen scientists and domain-specific scientists has assembled a dataset of ca. 250,000 potter's stamps from the Samian Research database, accessible with findspots and relevant bibliography as Linked Open Samian Ware (LOSW) via the collaborative LOD hub "archaeology.link".

For this purpose, a reproducible workflow (Fig. 2; Thiery *et al.* 2021) was developed to transform the Samian Ware data from its original relational structure into LOD and FAIR data (Wilkinson *et al.* 2016) to reuse the data. First, entries such as potter stamps are curated in an interactive web application

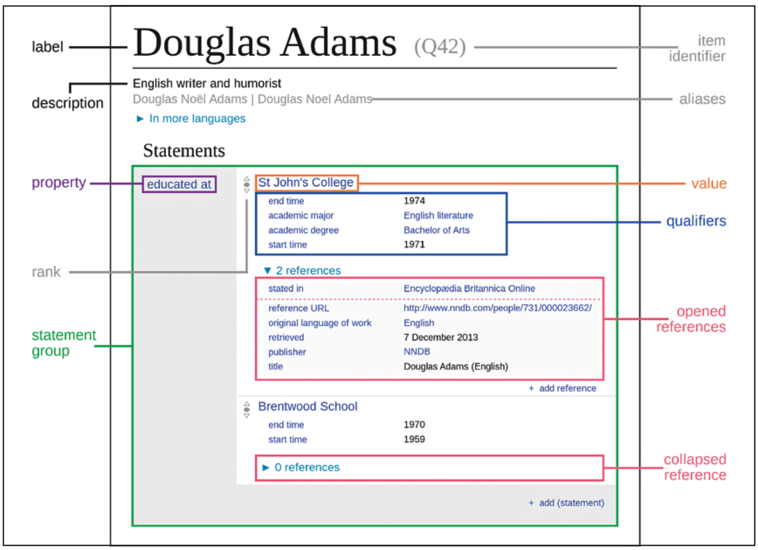


Fig. 1 – Graphic representing the data model in Wikidata with a statement group and opened references (C. Kritschmar, WMDE, via Wikimedia Commons).

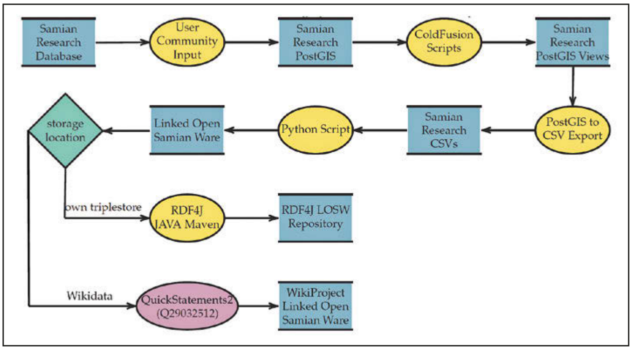


Fig. 2 – Linked Pipe: Linked Open Samian Ware, as data flow diagram using the Yourdon And/Or De Marco notation and the Linked Pipes style (via Thiery *et al.* 2021).

Samian Research and stored in a PostgreSQL database. Second, these data are exported to CSV files, which are then transformed to RDF using Python scripts according to the Samian Ontology (Thiery, Mees 2021). To share the data, two sub-workflows are implemented: (i) one leading to a self-hosted triple store, where the data is mapped to places in the Pleiades gazetteer and to Roman ceramic typologies in the Ceramic Typologies Ontology (CeraTyOnt) (Thiery *et al.* 2020), (ii) the other one to the Wikidata WikiProject "Linked Open Samian Ware" (Thiery, Mees 2022) using "QuickStatements" to transform the CSV data to Wikidata entries (Schmidt *et al.* 2022).

## 2. Samian Research in Wikidata

In 2020-2021, Samian Research began a process of integrating its data within Wikidata through the creation of a set of Samian Ware Wikidata items, including 3,874 Samian Ware Discovery Sites, 103 Samian Ware kiln sites and 13 kiln regions, comprising accurate or approximate geospatial information and a backlink to the LOD Hub "archaeology.link". Within Wikidata, geospatial classes describing Samian Ware data were created: Samian Ware Discovery Sites (Q102202066), production centres (kiln sites) as Samian Ware Production Centres (Q102202026), and kiln regions as Samian Ware Kilnregion (Q102201947). Each geospatial resource is also categorised as an "archaeological site" (Q839954) (Schmidt *et al.* 2022).

These three new classes are characterised by several unique attributes, identified as derived from the Samian Research database. Samian Ware Discovery Sites in Wikidata (Fig. 3) are instances of (P31) Samian Ware Discovery Site (Q102202066), are part of (P361) Samian Research (Q90412636) and have exact matches (P2888) as backlink to the Linked Open Samian Ware

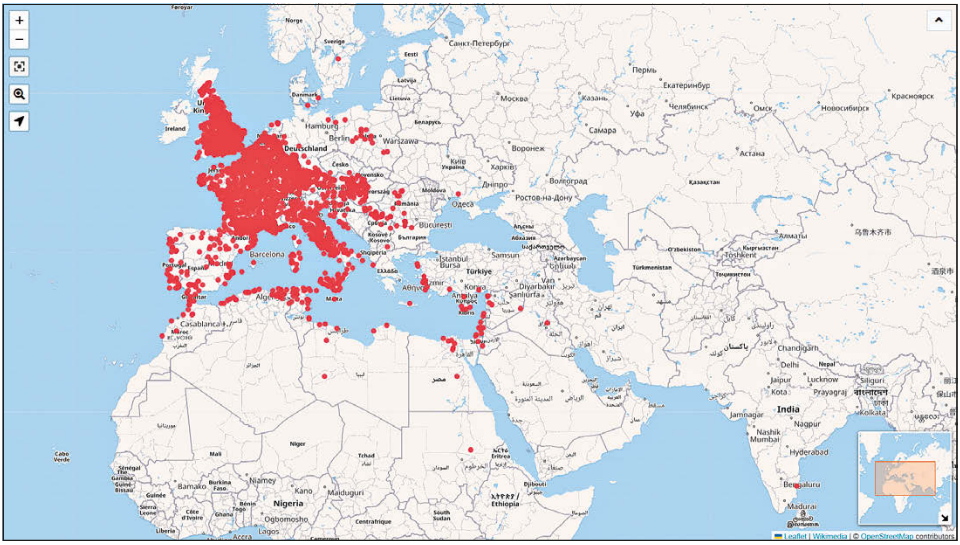


Fig. 3 – Linked Open Samian Ware Discovery Sites (red dots) on Wikidata queried via https://w.wiki/6EBu on 09/01/2023, Wikidata Community.


Fig. 4 – Linked Open Samian Ware Production Centres (red dots) on Wikidata queried via https://w.wiki/6EBx on 09/01/2023, Wikidata Community

URI, e.g. the Pompeii Samian Ware Discovery Site (Q103190089) with its URI http://data.archaeology.link/data/samian/loc_ds_1003977 (located at 40°45’00.0”N 14°28’60.0”E).

Samian Ware production centres in Wikidata (Fig. 4) are instances of (P31) a Samian Ware Production Centre (Q102202026). They are also part of (P361) Samian Research (Q90412636) and have exact matches (P2888) as backlink to the Linked Open Samian Ware URI, e.g. the La Graufesenque Samian Ware Production Centre (Q102763431) with its URI http://data.archaeology.link/data/samian/loc_pc_2000001 (located at 44°06’00.0”N 3°05’00.0”E). Samian Ware kiln regions in Wikidata (Fig. 5) are instances of (P31) a Samian Ware kiln region (Q102201947), are also part of (P361) Samian Research (Q90412636) and have exact matches (P2888) as backlink to the Linked Open Samian Ware URI. These kiln regions are calculated as a convex hull of production centres having the same regional tradition. The production centre La Graufesenque is part of the South Gaulish kiln region (http://data.archaeology.link/data/samian/loc_kr_131462; Q102764958) located in the S of modern France. In the Wikimedia Universe, this geospatial data is also stored in Wikimedia Commons as GeoShape GeoJSON, e.g., the before mentioned kiln region.

Creating designated Wikidata items is an efficient way to map the substantial geographic reach of our subject. It refers to many European archaeological sites and excavations which hitherto lacked a Wikidata identifier. For example,

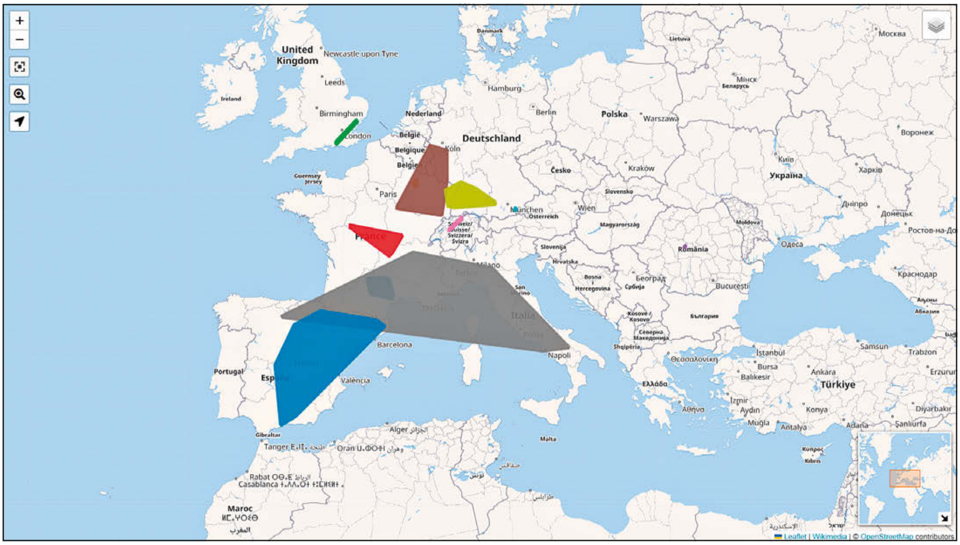


Fig. 5 – Linked Open Samian Ware kiln regions (coloured polygons) are calculated as a convex hull of production centres having the same regional tradition, on Wikidata queried via https://w.wiki/4pDu on 09/01/2023, Wikidata Community.

the Samian Ware Discovery Site “Saint-Georges-de-Reneins”. A new findspot in Samian Research from June 2022 has (currently) no “archaeological site” entity in Wikidata. This one-directional way, due to not directly declaring Wikidata entities in Samian Research, does not currently allow its sites to be merged automatically with existing Wikidata items for archaeological sites and excavations.

## 3. Use case: Corinth

The archaeological site of Corinth illustrates one obvious issue that has to be solved, e.g. the Corinth from Geonames with ID 259289 (https://www.geonames.org/259289/korinthos.html) is not the Corinth of ToposText Place ID 379229BEuB (https://topostext.org/place/379229BEuB) and not the Samian Ware Discovery Site Corinth with ID 1003935 (http://data.archaeology.link/data/samian/loc_ds_1003935). But how to create semantic clarity related to archaeological sites, also within Wikidata? Here, more than four overlapping concepts associated with very different Wikidata properties exist; 15 monuments in ancient Corinth have Wikidata items of their own, e.g., theatre, Asklepieion, the temple of Apollo, etc. The following entities are semantically and content related, but not the same:

– Corinth (Q1363688 - the ancient city in historical literature),
– ancient Corinth (Q22681231 - the modern village),
– ancient Corinth (Q101834062 - the organised archaeological site),
– the Corinth excavations (Q5170664 - archaeological excavation, an organised activity).

Semantic clarity can be created by highlighting four main items: excavations, sites, ancient and modern places:

– The excavations are the source of scientific information via scholars, publications, archives, and storerooms.
– The site is something one might visit, under specific circumstances, to see specific things.
– The ancient place has a vaguely defined territory but is associated with specific historical events and real or mythological people.
– The modern place, in Greece, usually re-baptised with an ancient name, has different properties: administrative, population, etc.

These main items cause challenges:

– Wikipedia editors like to combine – unlike Wikidata items – ancient and modern places and sites with their excavations.
– Wikidata editors create double and triple entities for maybe the same thing because they are a bit different. These have to be merged, e.g., Q103160025 as the created entity for the original Samian Ware Discovery Site Corinth (ID 1003935), which was merged into the archaeological site of Corinth (Q101834062).

– Good Linked Open Data keeps different entities separate, using properties to link them in a human and machine-readable way.
– Complete rigour is massively labour-intensive. We combine where two items would each have too little structured data to justify creating it.
– Rescue excavation in Athens is both an archaeological site (a street address) and a short-lived excavation producing limited archaeological data.

Currently, Wikidata entries (e.g., Pompeii - Q43332) combine the ancient city, the modern archaeological site, and excavations. The Wikidata item Q103190089 Pompeii (Samian Ware Discovery Site) does not link to Pompeii Q43332, the ancient city/ruins, except through a shared Pleiades ID and similar coordinates. Nor does Q43332 link to Q103190089. The future praxis should ideally be that "Samian Ware Discovery Sites" are linked via Wikidata to the excavation, which documents the presence of this ware and/or to the archaeological site. We find 2,916 Wikidata items for archaeological sites in Italy but only 5 archaeological excavations. The latter concept is used (for now) primarily in Greece. Meanwhile, ca. 300 Samian Ware site items for Italy. Most could be combined with other Wikidata items if we choose.

## 4. Conclusion and outlook

To solve these issues, the broader Wikidata Community must be enlisted. Wikidata properties and items suffice for almost the full range of Roman ceramics data, reflecting the diverse and active communities of users but also diverse implementations of data models. Knowledge exchange must be enabled, e.g., by bidirectional links using properties in Wikidata. We currently use P2888 (exact match) which causes problems with multiple assignments. A solution to this can be creating an "archaeology.link property", allowing for multiple exact matches, which remains to be discussed within the Wikidata community. However, in a specialised domain, can community-validated data entries safely generate new knowledge? We think it does, because it may result in information from researchers familiar with the local situation, from which specific excavation in Corinth a particular Samian research object may originate and to add this information to the archaeological Linked Open Data Cloud. We consider Wikidata Community projects in archaeology (Trognitz *et al.* 2023) as an umbrella for community initiatives, e.g., Linked Open Samian Ware to address issues of sustainability and data consistency.

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## ABSTRACT

In 2020, the Samian Research database began a process of integrating its data within Wikidata through the creation of a set of Samian Research Wikidata items, including Samian Ware Discovery Sites, Samian Ware kiln sites and kiln regions, comprising accurate or approximate geospatial information and a backlink to the Linked Open Data hub 'archaeology.link'. This approach of creating designated Wikidata items is an efficient way to map the enormous geographic reach of our subject and to call attention to many European archaeological sites and excavations that hitherto lacked a Wikidata identifier. The site of Corinth illustrates an exemplary issue to be solved: ambiguity and different archaeological concepts and ideas. E.g., is it correct to merge Corinth as a Samian Ware Discovery Site with the archaeological site of ancient Corinth? To solve the issue, the broader Wikidata community must be enlisted. This paper describes the challenges in the use case of Corinth and offers solutions within Wikidata.

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# LA VALORIZZAZIONE DEI MUSEI LOCALI ATTRAVERSO WIKIPEDIA: IL PROGETTO MEDANIENE

## 1. Il progetto sistema museale del MedAniene

Nell'agosto del 2022, nell'ambito della ventiseiesima assemblea generale tenutasi a Praga, la commissione ICOM (International Council of Museums, https://www.icom-italia.org/) ha approvato una nuova definizione di museo, nella quale viene posto in evidenza il cambiamento del ruolo di questa istituzione nei confronti della società, pur mantenendo una continuità con la definizione precedente: sono stati infatti introdotti termini e attività che identificano una maggiore partecipazione delle comunità alle attività museali e la condivisione della conoscenza è indicata come compito e obiettivo fondamentale (https://icom.museum/en/news/icom-approves-a-new-museum-definition/). In questa cornice si inserisce il progetto MedAniene, qui presentato, focalizzato sulla valorizzazione e sulla comunicazione di sette piccoli musei situati nella Valle dell'Aniene, in provincia di Roma, attraverso l'uso collaborativo degli strumenti wiki, condividendo e perseguendo, quindi, gli obiettivi enunciati da ICOM.

Il progetto ha previsto la creazione *ex novo* o l'implementazione delle pagine Wikipedia, l'acquisizione fotografica delle collezioni museali e il relativo caricamento di immagini nel repository Wikimedia Commons e la strutturazione di informazioni relazionali all'interno della piattaforma WikiData (https://www.wikidata.org/wiki/Wikidata:Main_Page). I musei coinvolti sono: Museo delle Culture Villa Garibaldi di Riofreddo (https://www.compagniadeilepini.it/sistema-demos-museo-delle-culture-comune-di-riofreddo/), Museo delle Tradizioni Musicali di Arsoli, Museo della Civiltà Contadina Valle dell'Aniene di Roviano, Museo Civico di Arte Moderna e Contemporanea di Anticoli Corrado, Museo delle Attività cartarie e della Stampa nella Rocca Abbaziale di Subiaco, Museo Civico Archeologico Villa di Traiano ad Arcinazzo e Museo Demo Etnoantropologico Castrum Vivarii a Vivaro Romano. Questa rete museale ha condiviso l'obiettivo di migliorare la comunicazione e aumentare la visibilità, fornendo al pubblico informazioni scientifiche in modalità open access, costruendo al contempo un'infrastruttura digitale in grado di fruire della relazionalità delle informazioni utilizzando WikiData come provider di dati e connessioni tra i diversi elementi creati o modificati all'interno dell'ecosistema dei progetti wiki.

Essere presenti all'interno di questo ecosistema informativo risulta essere di fondamentale importanza per la diffusione della conoscenza di siti culturali, soprattutto di piccole realtà museali, sia per il coinvolgimento delle relative comunità, sia per il raggiungimento di nuovi potenziali pubblici, data l'ampia diffusione e consultazione dei progetti Wikimedia – si pensi a quante volte viene consultata Wikipedia prima di intraprendere un viaggio o nel momento in cui si attraversa un territorio. Un altro aspetto da evidenziare è la connessione con sistemi di ricerca e processi euristici relazionali: si ha così la possibilità di offrire dati aggiornati e condivisi anche a chi non accede direttamente, ad esempio, alle relative pagine Wikipedia dei musei, ma si ferma ai risultati di ricerca di Google, con le anteprime informative.

MedAniene è stato un primo esperimento operativo di costruzione di infrastrutture di conoscenza dal basso, promosso dall'APS ArcheoFOSS. L'avere finalmente una personalità giuridica ha permesso di catalizzare gli sforzi dei volontari grazie alla possibilità di accedere direttamente a fondi per la valorizzazione, instaurando un'attività collaborativa che ha visto una sinergia virtuosa con altri operatori della conoscenza libera, italiani e internazionali, come l'associazione Wikimedia Italia.

La prima fase del progetto ha previsto la formazione specifica di un gruppo di lavoro, composto da diversi professionisti, tra cui le autrici, coinvolto nelle problematiche inerenti al software free, libre e open source e sulle licenze aperte, che regolano il mondo wiki e open access; quindi un'attività più specifica sugli standard e regole di scrittura wiki che riguardano la creazione, la modifica o l'implementazione di una pagina, nuova o già esistente su Wikipedia. La parte di sistemazione organica e relazionale, incentrata su WikiData, è stata il punto di arrivo di un percorso di apprendimento e divulgazione, con una precisa strategia informativa relazionale. Sebbene aperte alla libera contribuzione e senza gerarchie redazionali, le piattaforme wiki hanno un codice di condotta stabilito; in particolare le linee guida di Wikipedia si basano su cinque pilastri fondamentali (https://it.wikipedia.org/wiki/Wikipedia:Cinque_pilastri), con relativi corollari: i) Wikipedia è un'enciclopedia; ii) Wikipedia ha un punto di vista neutrale; iii) Wikipedia è libera; iv) Wikipedia ha un codice di condotta; v) Wikipedia non ha regole fisse, eccetto i cinque principi elencati. Tenendo conto di questi semplici indirizzi di comportamento, nel rispetto del lavoro della comunità wiki, si è quindi proceduto a sensibilizzare e formare in tal senso i volontari che hanno costituito il gruppo di lavoro progettuale.

## 2. Metodologia e realizzazione del progetto

La successiva fase di realizzazione del progetto ha visto coinvolti i diversi componenti del gruppo in un lavoro di ricerca e in un successivo sopralluogo presso i musei. Ogni ricercatore prima di recarsi *in loco* per i sopralluoghi, ha, infatti, esaminato le pagine Wikipedia, ove già esistenti e le informazioni presenti online sui siti dedicati ai diversi enti. Tale valutazione è stata propedeutica per l'impostazione del successivo lavoro di ricerca, di collazione del materiale e di scrittura per comunicare al meglio le collezioni. Il rapporto con i direttori è stato particolarmente importante per focalizzare i punti forti dei musei e valorizzarli all'interno delle pagine: questi hanno permesso il caricamento con licenza libera dei loghi, inseriti successivamente nelle diverse pagine Wikipedia e utili anche a identificare come ufficiali le pagine create.

Successivamente sono stati organizzati i sopralluoghi, al fine non solo di visionare il materiale e raccogliere ulteriore documentazione, ma anche per conoscere da vicino il potenziale culturale e le tante peculiarità di un territorio ricco di cultura come la Valle dell'Aniene. Grazie a questa attività è stato possibile realizzare indici bibliografici essenziali, che sono stati utilizzati per la creazione delle pagine stesse e quindi inseriti come riferimenti bibliografici dei musei, costruendo anche un utile apparato bibliografico per chi avrà necessità di maggiori informazioni sulle collezioni (Indrio 1995; AA.VV. 2001, 2008; Caruso 2008).

Il processo di ricerca è stato inoltre prezioso per instaurare relazioni con gli operatori e le guide dei musei del MedAniene. Per i volontari coinvolti nel progetto è stata un'occasione per portare avanti i contatti con le strutture museali per motivi di ricerca, pensare nuovi progetti e supportare attività di sviluppo multimediale delle strutture stesse, grazie al riutilizzo di quanto raccolto durante il progetto stesso e liberamente condiviso con licenze aperte. Si è così concretizzato il potenziale di accrescimento culturale mediante il riutilizzo di dati e informazioni rilasciati con licenza Creative Commons (https://creativecommons.it/chapterIT/): le ricognizioni sono infatti servite anche alla produzione di nuovo materiale fotografico ad alta risoluzione. Si è potuta così rinnovare la presentazione delle sale museali online e mostrare in alta risoluzione i dettagli, la varietà e la qualità culturale degli oggetti esposti (Fig. 1).

Dopo la selezione, le immagini che avrebbero arricchito i testi nelle pagine Wikipedia sono state caricate e metadatate in Wikimedia Commons, specificando l'autore, il luogo di scatto e i diritti d'uso delle immagini. Wikimedia Commons è un archivio digitale dove è possibile caricare elementi multimediali come immagini, video o suoni: ciò avviene attraverso un processo guidato di metadatazione e ricognizione dei diritti d'uso che, in alcuni casi, porta a dover produrre documentazioni che dimostrino l'autorizzazione alla condivisione aperta dei materiali. Le piattaforme e gli strumenti Wikimedia sono particolarmente adatti all'implementazione di una politica di open data nelle istituzioni culturali.

Fig. 1 – Sala delle Carceri del Civico Museo d'Arte Moderna e Contemporanea di Anticoli Corrado, da Wikimedia Commons (foto R. Manzollino).

I contenuti sono facili da gestire e condividere, gli strumenti sono gratuiti e gestiti dalla piattaforma: si può così dedicare maggiore attenzione all'argomento e creare molti collegamenti con una comunità internazionale (Albore *et al.* 2021).

Fotografare e pubblicare in modalità open immagini sulle piattaforme wiki influisce sulla creazione di nuovo materiale editoriale, come è dimostrato dal caso del Museo delle Culture Villa Garibaldi di Riofreddo: la relativa voce Wikipedia è stata utilizzata per la redazione del nuovo contenuto editoriale del Sistema Demos (https://www.compagniadeilepini.it/sistema-demos-museo-delle-culture-comune-di-riofreddo/). Contenuti condivisi con licenza libera possono anche avere valenza scientifica: per il Museo di Arsoli, alcune delle fotografie scattate sono state poi adoperate per la schedatura di oggetti presso l'ICCD. I testi, le immagini e i dati aggiunti alle pagine di Wikipedia possono essere immediatamente riutilizzati, citati e linkati da terzi con licenza CC BY-SA 3.0, concessa dai direttori. Grazie a questa licenza i contenuti possono essere condivisi e utilizzati, ad esempio, da guide locali o altri media online, sia all'interno che all'esterno dei progetti wiki, citando la fonte e creando quindi una maggiore connessione e possibilità di valorizzazione e conoscenza delle collezioni.

Un'importante funzione di Wikimedia Commons, motivo ulteriore per cui si è deciso di realizzare il progetto e condividere le informazioni, è quello di consentire di creare delle strutture logiche con le quali è possibile trovare i risultati di una ricerca. Le informazioni, infatti, vengono gerarchizzate e la stessa operazione viene fatta per i dati. Essi possono essere inseriti in un database, WikiData, dove le informazioni sono strutturate in modo relazionale. Nelle schede si possono specificare diverse proprietà per ogni elemento, fino ad arrivare alla caratterizzazione più particolare e pertinente dell'elemento stesso. Durante le azioni di progetto sono state dunque create diverse categorie per l'indicizzazione su Wikipedia e sul web, sia delle pagine che dei contenuti relativi ai singoli musei, operazione utile per futuri aggiornamenti delle informazioni e per velocizzare le funzioni euristiche attraverso i vari motori di ricerca. L'indicizzazione e la formazione di cataloghi online accessibili e gratuiti permettono di far risaltare le collezioni, includendo anche le comunità che vorranno contribuire all'aggiornamento e avvicinando allo stesso tempo un nuovo pubblico di persone interessate (Albore *et al.* 2021).

Una volta terminate le correzioni delle pagine, create e categorizzate le nuove voci e le immagini, definiti i diritti d'uso, si è proceduto a redigere o completare e aggiornare i testi e all'organizzazione delle pagine. Si è rivolta particolare attenzione all'integrazione delle pagine Wikipedia che riportano argomenti affini, creando relazioni con altre pagine e portando così a una maggiore possibilità di far conoscere i musei. Il materiale edito è stato inviato ai direttori per la revisione dei contenuti. Tale insieme di operazioni ha condotto ad un arricchimento delle voci dal punto di vista scientifico, grazie alla collaborazione con esperti del settore. La fase finale ha visto, infine, la formattazione, l'uniformazione definitiva delle pagine e la loro pubblicazione[1].

[1] Anticoli Corrado: https://it.wikipedia.org/wiki/Civico_Museo_d%27Arte_Moderna_e_Contemporanea; Arcinazzo: https://it.wikipedia.org/wiki/Villa_di_Traiano; https://it.wikipedia.org/wiki/Museo_Civico_Archeologico_Villa_di_Traiano; Arsoli: https://it.wikipedia.org/wiki/Museo_delle_Tradizioni_Musicali_(Arsoli); Riofreddo: https://it.wikipedia.org/wiki/Museo_delle_Culture_Villa_Garibaldi; Roviano: https://it.wikipedia.org/wiki/Museo_della_civilt%C3%A0_contadina_Valle_dell%27Aniene; Subiaco: https://it.wikipedia.org/wiki/Museo_delle_Attivit%C3%A0_Cartarie_e_della_Stampa; Vivaro Romano: https://it.wikipedia.org/wiki/Museo_Castrum_Vivarii.

## 3. Risultati e conclusioni

### 3.1 *Analisi delle frequenze di visualizzazione delle pagine*

Un ulteriore obiettivo del progetto è stato l'avvio di un'analisi dell'impatto che la creazione o implementazione di contenuti nelle piattaforme Wikipedia hanno avuto sul fruitore esterno e sulla collettività che insiste sul medesimo territorio (Rosati 2021). È stata utilizzata la piattaforma https://pageviews.wmcloud.org, la quale consente di avere un quadro complessivo delle visualizzazioni riguardanti ogni pagina creata su Wikipedia. Sono stati presi in esame due casi studio: la Villa di Traiano ad Arcinazzo e il Museo Civico di Arte Moderna e Contemporanea di Anticoli Corrado, le cui pagine Wikipedia sono state aggiornate durante il progetto.

All'interno dello strumento di pageviews è possibile settare il range cronologico entro il quale si vogliono effettuare le analisi statistiche, la tipologia di data (giornaliera, settimanale, mensile), il nome del progetto Wikipedia dal quale trarre queste informazioni, con possibilità di scelta tra i molteplici progetti wiki (Wikivoyage, Wikidata, etc.), per quali device sono disponibili le analisi statistiche e, infine, il profilo dell'utenza che effettua la ricerca.

Ai fini dello studio si è deciso di impostare un'analisi mensile, esaminando in particolare il periodo cronologico da febbraio 2022 a dicembre 2022, quindi subito dopo la pubblicazione delle prime pagine; come progetto, invece, è stato inserito il sito di Wikipedia nel quale sono state create le pagine. Al centro della scheda risultante dall'analisi è possibile visualizzare le statistiche, presentate sotto forma di istogramma, dal quale sono desumibili quante visualizzazioni sono state presenti per ogni mese. A destra della scheda, inoltre, si trovano sia il numero totale che il numero medio di visita alla pagina riguardante il range cronologico scelto.

### 3.2 *Analisi dei dati statistici*

Per quanto riguarda il caso studio della Villa di Traiano, è stato possibile notare come il mese di agosto presenti un numero maggiore di visualizzazioni (382). Questo picco si può in parte spiegare in quanto gli Altipiani di Arcinazzo Romano sono una meta di villeggiatura molto frequentata nei mesi estivi (Fig. 2). La pagina del Museo Civico di Arte Moderna e Contemporanea di Anticoli Corrado ha totalizzato, invece, dalla sua creazione 518 visualizzazioni, con una media mensile di 47 visite (Fig. 3). Il mese che ha ottenuto maggiori visualizzazioni è stato quello di ottobre, in cui si è tenuta una mostra omaggio alla figura del pittore Giuseppe Capogrossi, artista romano che frequentò il paese "degli artisti e

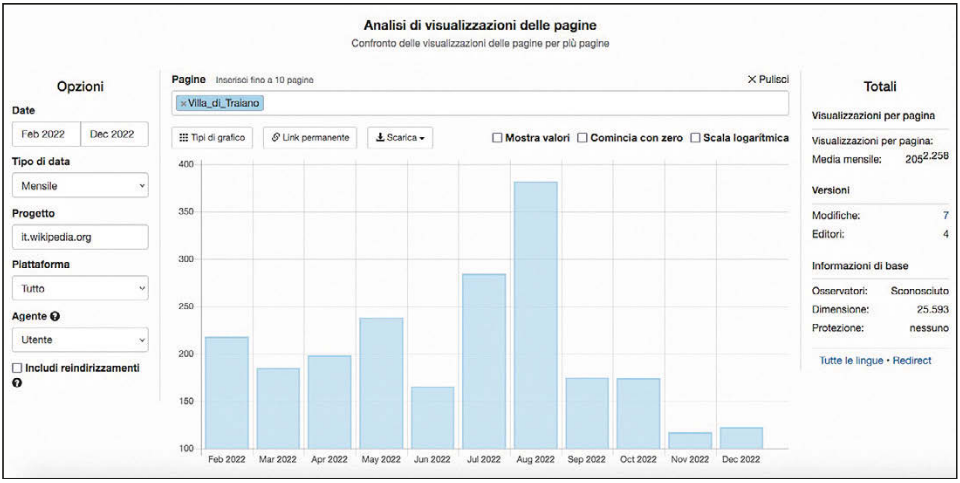


Fig. 2 – Istogramma con i dati riguardanti le visualizzazioni della pagina Wikipedia della Villa di Traiano presente ad Arcinazzo Romano (https://pageviews.wmcloud.org).

modelle"[2] a partire dal 1923 e che potrebbe aver portato ad una maggiore attenzione verso il museo e la sua collezione.

L'analisi dei dati è in costante monitoraggio dal gruppo di ricerca interno all'APS ArcheoFOSS per analizzare se il lavoro svolto influisce effettivamente sull'incremento del turismo dei territori oggetto di studio, attraverso il confronto dei flussi di pubblico online e dei dati provenienti dagli ingressi al Museo. Le analisi 2023 sui dati dei visitatori presso gli altri siti del progetto sono in fase di pubblicazione. A titolo esemplificativo, il Museo Civico di Riofreddo Villa Garibaldi, nell'anno 2022, ha registrato un incremento rispetto al 2020 del 299,15%, rispetto al 2021 del 91,4% (su questi dati naturalmente pesa la chiusura forzata causata dal COVID-19), mentre rispetto al 2019 si è avuto un incremento del 13,35%. La comparazione relativa con quest'ultimo dato, nel quale non esisteva ancora una pagina wiki del museo e sul quale non grava l'elemento pandemico, denota un incremento in linea con uno studio preliminare relativo ad altri contesti territoriali, pubblicato nel 2021, dove viene segnalata una crescita media del 9% annuo (Hinnosar *et al.* 2021).

L'incremento registrato nel 2022 a Riofreddo non è naturalmente imputabile esclusivamente alla creazione della pagina Wikipedia del suo Museo; tuttavia, il progetto ha sicuramente contribuito ad aumentare la

[2] L'Unità, 12 agosto 2007 Archiviato il 1° febbraio 2014 in Internet Archive: https://it.wikipedia.org/wiki/Anticoli_Corrado

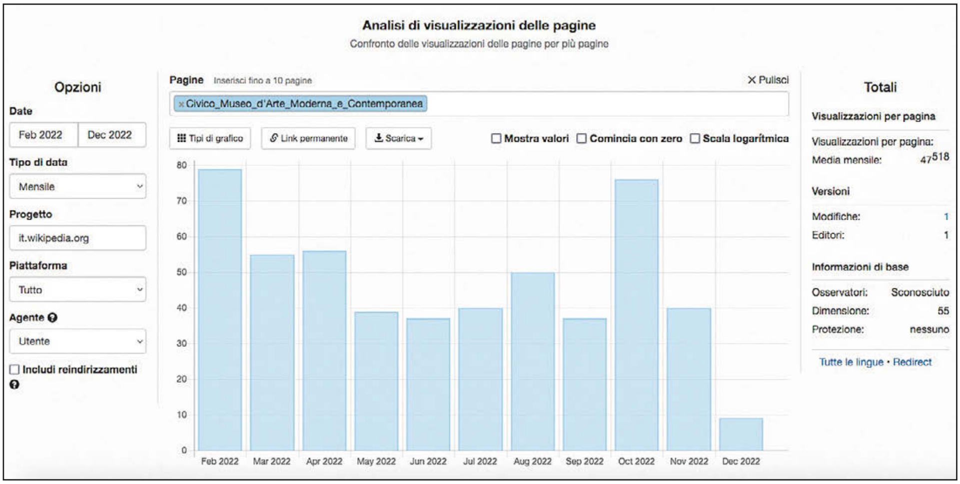


Fig. 3 – Istogramma con i dati riguardanti le visualizzazioni della pagina Wikipedia del Museo Civico d'Arte Moderna e Contemporanea di Anticoli Corrado (https://pageviews.wmcloud.org).

sua visibilità. Per gli altri siti saranno costruite delle statistiche *ad hoc* in base alla prossima pubblicazione ISTAT dei dati annuali dei flussi di visita avvenuti nel 2022.

## 4. Conclusioni

La visibilità che i musei possono tuttora ottenere grazie a Wikipedia (Hinnosar *et al.* 2021) aiuta a comprendere quanto, attraverso progetti simili a quello descritto, si possano incentivare nuove visite e incrementi turistici anche in aree meno note, generando possibilità nell'aumento degli ingressi e dello studio stesso delle collezioni da altri esperti del settore. A febbraio 2023 Wikimedia Italia ha promosso, in collaborazione con Icom Italia e Creative Commons Italia, un'iniziativa dal titolo *Tutti i musei su Wikipedia* (https://www.wikimedia.it/tutti-i-musei-su-wikipedia-aderisci-al-progetto/) volta ad ampliare la conoscenza dei musei italiani, mostrando l'importanza e le possibilità derivanti da contenuti ad accesso libero in ambito culturale. Questi obiettivi rappresentano esattamente gli intenti presentati nel progetto e anche del processo di lavoro presentato, in cui grande importanza si è data alle comunità di riferimento e alle direzioni museali nella stesura dei contenuti, condividendo un medesimo intento di partecipazione e collaborazione per la diffusione della conoscenza.

Il progetto del MedAniene ha permesso, dunque, di creare un primo confronto per queste realtà attraverso strumenti di comunicazione digitale e ha consentito di presentare una nuova modalità di condivisione dei propri contenuti in open access. Inoltre, la valutazione sull'impatto delle visualizzazioni alle pagine, la cui visibilità è aumentata anche negli altri musei del progetto qui non analizzati, ha permesso di offrire delle nuove possibilità di valorizzazione turistica del territorio e dei musei, coinvolgendo le comunità e fornendo un nuovo strumento di comunicazione.

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## ABSTRACT

The aim of this contribution is to explain workflows, methodologies and impact of the 'MedAniene Project', that was realised through the collaborative use of Wiki platforms and coordinated by the APS ArcheoFOSS. The project involved creating or modifying Wikipedia pages for the museums of the Aniene Valley, uploading images to the Wikimedia Commons repository and structuring relational information in the Wikidata system. The goal of the work was to improve the communication and increase the visibility of those museums by provid-

ing the public with open access scientific explanations and implementing data relationships through several heuristic systems which are available to the digital audience. Building such an informative apparatus offers the opportunity to learn about shared digital cultural heritage, increasing awareness in external users and in communities. It is now possible to analyse data on views, accesses and clicks on contents and evaluate the impact of specific activities in terms of audience targeting and engagement. Indeed, this work proposes a methodology for the establishment of a digital, open and collaborative communication space, improving the connection between cultural entities and communities.

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# THE ROAD (NOT) TAKEN. RECONSTRUCTING PRE-MODERN ROADS IN VIABUNDUS. METHODS AND OPPORTUNITIES

## 1. Introduction

The Viabundus project (www.viabundus.eu), which was initiated in 2019 as a collaboration between the University of Göttingen and the Research Centre for Hanse and Baltic History Lübeck, provides a digital infrastructure for the research into pre-modern traffic and mobility in Northern and Central Europe in the period of 1350-1650. A first version of the growing platform has been launched in 2021 and is currently running its second update. The map and its underlying database consist of several elements, most prominently the reconstructed routes of pre-modern highways.

Pre-modern mobility has long been an issue in all historic disciplines and has been discussed in several different contexts. Since mobility is not a static construct and its nature is movement within time and space, visualizing it on maps has always been a difficult task in research. Even though roads tend to show a high path dependency in terms of trajectory and frequentation, they bring their own methodological challenges when it comes to mapping. The static and two-dimensional nature of maps, however, brings its own problems that need to be reflected in any endeavor that relies heavily on them.

In Germany, attempts at the reconstruction of roads go back to the field of Historical Geography (Denecke 2019), mostly and most accurately on a regional level (recently Fütterer 2016; Herzog 2017), some more on a super-regional level, such as the *Atlas Hansische Handelsstraßen* (Bruns, Weczerka 1962), on which Viabundus is based. Archaeological research focuses on Roman roads, either those that survived or probable trajectories, reconstructed by use of Least Cost Path Analysis (Verhagen *et al.* 2019). Projects that inspired Viabundus include ORBIS The Stanford Geospatial Network Model of the Roman World (https://orbis.stanford.edu/) and viator-e (https://viatore.icac.cat/map/).

While the general layout and data structure of the Viabundus project have been described elsewhere (Holterman *et al.* 2022), this paper will focus more on the exact methods and associated problems in the reconstruction of roads, as well as show a quick and rudimentary application of the Viabundus-data in combination with data on pilgrim badges provided by courtesy of the Kunera project[1].

[1] We thank the colleagues from the Kunera project for the dataset used in this article. Please visit https://kunera.nl/en for their online viewing tool.

## 2. Reconstructing roads. methods, problems and perspectives

As with any reconstruction of roads, it has to be kept in mind that the results do not necessarily show an accurate historical situation, but rather give us an idea of routes. Routes in this case are meant as the general direction of travel, the idea of the direction one had to take in order to arrive at the destination. The road in this regard is the exact path within the terrain, which is heavily defined by geographical conditions. Following this understanding, roads are highly variable due to changing geographical or climate conditions (Robert 2009). Several roads can run along the same route and in fact, it has to be assumed that the road network consists of parallel-running roads that lead to a destination in a poly-linear fashion (Fütterer 2016). This presents a problem within any mapping endeavor: while it may be the aim to be as accurate as possible within the visualization, showing the trajectory of every road within a route could lead to very unclear and confusing maps. On the other hand, only showing one example of a road consolidates the very modern, but false, impression that there was one "right" way to choose in order to arrive at one's destination, much in the sense of a modern highway.

Since this dichotomy cannot be solved at this point, it is important to stress that the displayed connections within Viabundus are routes. Keeping this in mind, there are some general guidelines which may lead to more accurate road reconstructions which help make some educated guesses at the historical course of a road. Depending on the researcher's background and access to sources, the approaches to the reconstruction of roads may differ: the traditional historical approach entails the mapping of stations along a road mentioned in the sources, while the archaeological approach focuses on the mapping of road relics in the field. It has been long acknowledged that the combination of several approaches yields the most accurate results.

### 2.1 *Reconstruction based on written sources*

Especially for the reconstruction of medieval roads, researchers are in the fortunate situation to have access to written sources that describe historic travel routes. For the Early Middle Ages, royal itineraries feature prominently, which are joined by toll accounts in the High and Late Middle Ages; personal travel accounts complete the broad scope of sources that give us insight into medieval travel. There are several works that have used exactly these sources to scrutinize medieval mobility, with very interesting results. While questions concerning the practice of ruling in itinerant kingship, strategies of economic control or cultural contact (Müller-Mertens 1980; Reichert, Stolberg-Vowinckel 2009; Straube 2015) can be adressed, there are precious few mentions of roads themselves. Mapping the mentioned places usually results in straight lines leading from A to B with no idea of the actual path taken. The picture within the source material needs to be refined by supplementing the rather general images with the knowledge of infrastructure or overlaying several known travel itineraries, or by synchronizing itineraries with known road relics.

### 2.2 *Reconstruction based on maps*

Large quantities of the mapping in Viabundus have been undertaken using the retrogressive method of referencing historical maps. However, the first known maps tend to be more or less symbolic representations of the world, which were not necessarily meant to be used by travelers (Baumgärtner 2008). Even maps from the 16th century, which appear to represent the first geographically accurate visualizations of the landscape, tend to be simplified or idealized, since they were still not meant for travel orientation. The first measured and triangulated maps only start to emerge at the beginning of the 19th century, which are therefore the first maps that can be used for the reconstruction of roads. Only in the Low Countries and Flanders, the first triangulated maps were created in the 16th century, most notably by Jacob van Deventer, whose maps were largely used in the research of Dutch Viabundus.

However, this does not necessarily mean that the roads reconstructed from maps all stem from the 17th century. It can be assumed that several roads already existed and have existed for a while by the time they were mapped. Historical records may give indications in this regard, as well as the founding dates of towns and villages or the mention of bridge tolls, watchtowers or inns that lie along the roads, which are also recorded within Viabundus. Only with the beginning of the 18th century and the emergence of causeways that were much more straightforward than the preceding poly-linear roads, a careful review of the roads is in order. While causeways much more resemble modern highways in that they were built regardless of geographic obstacles, some may have been founded on medieval roads, while others were entirely new creations. However, even in these "newer" maps, medieval roads can still be found. They are usually displayed as secondary roads and appear much more crooked than the orderly causeways.

### 2.3 *Reconstruction based on infrastructure*

Traffic-related infrastructural elements provide a necessary addition to the reconstruction of roads. While written sources may remain vague, the knowledge of such infrastructure gives us a clearer idea of where a road may have had its course. However, "infrastructure" is quite a broad term in this context. While the discussion on how well different points of infrastructure indicate the existence of a road must take place elsewhere, in Viabundus some specific elements were taken into account (Fig. 1). These include first and foremost settlements (including castles, monasteries or watchtowers) and

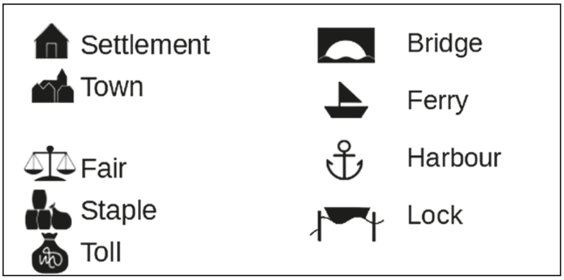


Fig. 1 – List of attributes recorded in Viabundus.

towns, which are the backbone of the traffic network, but also traffic facilities like bridges, ferries or fords, controlling instances like toll stations or staples, as well as economic focal points, such fairs or harbors.

In addition to scattered mentions within primary sources, information on such points of infrastructure may be derived from different areas: There are works that deal specifically with toll and customs stations (Pfeiffer 2015; Straube 2015). Other local studies that often describe infrastructural elements are the histories of towns. Historical maps may also indicate the existence of vanished infrastructure and therefore give a starting point for the search for those facilities. In the course of Viabundus' creation, it has become more and more apparent that a street map cannot be complete without the corresponding infrastructure, which prompted the attempt at the inclusion of thorough information on the points mentioned above.

### 2.4 *Reconstruction based on archaeological methods*

Road relics in the terrain let us reconstruct historic courses of roads quite accurately and have given us a good idea on where medieval roads can be found. Based on the findings of physical road relics, there are some general observations one can follow that make the course of a road plausible (Denecke 1969, 1979). Some observations include that roads tended to avoid wet river valley areas, as these were prone to flooding. A much more reliable path was found on the watersheds of rivers, for which even steep inclines were overcome. We can see the formation of holloways at such inclines and oftentimes, such holloways run parallel to each other, which indicates the continued usage of certain ascents. Modern digital data, such as Digital Terrain Models (DTM) based on aerial photographs and Lidar scanning, are a widely-spread tool to identify such creases and holloways in the terrain.

The main problem with road relics however, is that of dating. While the relation of holloways to each other may tell us about their relative chronology, in most cases only tangible finds may make absolute dating possible. Most often, the knowledge of such road relics is the result of personal inspection of researchers or the analysis of digital terrain models or Lidar-scans; systematic excavations or surveys are rarely undertaken, which then do not yield any findings.

For medieval roads, excavations outside urban areas are rare. Due to the lack of pavement and the fluctuating character of the unpaved roads, it is hard to pinpoint the location for an excavation. Additionally, there is the question on what one hopes to achieve by excavating what is essentially a dirt road. In the end, the holloway merely shows us a pre-modern pathway, but we rarely know how old it really is. Therefore, the information on specific road relics in Viabundus is equally sparse.

## 3. Highway to salvation: case study on pilgrims and roads

The potential of Viabundus lies not only in the visualization of medieval roads, road systems and networks, but also in the possibility of combining it with other datasets that relate to mobility. Kunera (https://kunera.nl/en) is a database with a free web application by the Radboud University in Nijmegen (NL). It collects and visualizes the points of origin, as well as the finding places of medieval pilgrim badges and *ampullae*, therefore serving as a database on medieval visual culture as well as pilgrimage. As a focal point of medieval mobility, pilgrimage appears to be one of the natural crossover points with Viabundus.

While the combination of the data does not answer questions per se, it does lead in interesting directions. First of all, the main and most basic point of interest would be how the finding and production places of pilgrim badges relate to the roads mapped in Viabundus. This opens questions to the traveling routes of pilgrims (Figs. 2, 3). The simple co-visualization of Viabundus and Kunera-data already gives us first insights[2]. Using the well-researched area of the Netherlands as an example, one can clearly see how a majority of both the finding places and the origins of pilgrim badges correlate with the roads mapped in Viabundus. This is especially striking since the data in this map is not differentiated by date, i.e. the mostly late-medieval roads seem to correlate with the high to late medieval pilgrim badges, indicating that the routes seem to be older than originally thought and show a high persistence. Though some locations of pilgrim badges appear to be just off the roads, this does not mean that the data is not accurate: Viabundus maps the main roads apt for long-distance traffic on carts and wagons and not several parallel routes and footpaths that lead to and from the main road.

Given the fact that the intention of the Viabundus project was to facilitate research in economic history, it is quite interesting how well the dataset

[2] The data used for this paper is based on Viabundus version 1.2 from 21.09.2022.

Fig. 2 – Origin places of pilgrim badges in the Netherlands with the traffic network 1350-1650.

Fig. 3 – Finding places of pilgrim badges in the Netherlands.

matches with the mobility of pilgrims (who are a mostly urban phenomenon). Religious mobility seems to have moved along the same lines as traders. This gives rise to the question whether we can think religious and economic mobility as separate entities or if the infrastructure provided for pilgrims were also welcome amenities to trading caravans and the like. Others have already pointed out that commercial accommodation, i.e. inns, were the result of an increasing number of pilgrims on medieval roads and the fact that Christian establishments like hospitals and monasteries were not able to accommodate the masses anymore (Schmugge 1983). Therefore, paid accommodation developed, which, in consequence, functioned as places of trade as well (Peyer 1987). This correlation suggests that «the merchant on a pilgrimage and the mercantile pilgrim merge into a lucky symbiosis» (Schmugge 1983, 59; translation by author). It is therefore only natural that the same routes were used. The fact that most of the origin sites of pilgrim badges find themselves along the same routes as well suggests that it would not have been a difficult endeavor to combine pilgrimage and trade. Even if a large majority of pilgrims was not merchants, the data suggests that merchants and "full-time" pilgrims may have used the same routes and shared infrastructure.

## 4. Conclusion

While the reconstruction of pre-modern roads is an inaccurate science at its best, this article has shown that there are several approaches that lead to acceptable approximations of medieval roads. At the same time, for most applications a close approximation to a route may be more serviceable than the actual reconstruction of all historical roads that ran within an area. Viabundus aims to provide such approximations in the awareness of all methodological problems. Combining Viabundus data and Kunera data has shown the research potential within the street map. By correlating road data with existing data on other categories of material culture, new approaches to pre-modern mobility can be found and long-standing assumptions may be further solidified.

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## ABSTRACT

The Viabundus pre-modern street map attempts to show medieval and early modern traffic connections. However, mapping medieval and pre-modern land routes comes with methodological challenges which are reflected upon in this paper. The reconstruction is based on written and archaeological sources, historical maps, and establishments of traffic infrastructure. Correlating the data with the origin places and finding places of pilgrim badges shows the research potential of the endeavor, as the simple co-visualization of the data already provides interesting connecting points.

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# FROM THE *ITINERARIUM ANTONINI* AND AL-IDRISI TO THE MOVECOST PLUGIN: ROAD NETWORK ANALYSIS IN THE CASTRONOVO DI SICILIA AREA

## 1. Introduction

The Castronovo di Sicilia landscape has been the subject of an archaeogeographic analysis (Robert 2010; Chouquer, Wattaux 2013) in order to identify possible dynamics of transformation of the historical landscape attributable to different geopolitical contexts. Central to this analysis was the study of the road network elaborated by comparing data taken from traditional written sources with the Least Cost Path Analysis (LCPA) (Herzog 2013). First of all, the LCPA highlighted how the area at issue is located near the point where the least expensive natural paths that unite the island from N to S and from E to W meet (Fig. 1). Precisely this favourable location and this centrality along various routes have made the territory of Castronovo an important place of passage in all historical periods. The current municipality of Castronovo di Sicilia is in fact located halfway between Palermo and Agrigento, along the route that connects the island's two main centres on the N and S coast; it is also located along the main internal routes that connect Trapani and Marsala to the W and Catania and Syracuse to the E. Even today the centrality of this area is evidenced by the proximity to the SS189 road, which connects Palermo with Agrigento, largely exploiting the natural path of the Platani valley.

## 2. VIII-Item ab Agrigento Lilybaeo

The current route of the SS189, in fact, partly follows one of the main internal communication routes of the Roman era, as recorded by the *Itinerarium Antonini* in the *VIII-Item ab Agrigento Lilybaeo*. According to G. Uggeri (2004, 97-116), who was the first to study the itinerary, later followed by L. Stangati, the path started from Agrigento and headed N, passing between Aragona and Comitini, where the *statio Pitinianis* must have been located (10 miles away from Agrigento, that is only one mile further than what was listed in the *Itinerarium*). From here, according to L. Stangati (2007, 221-222), the route continued N until it was divided into two branches, before meeting the Platani River. The westernmost branch headed towards Cantarello, where the Arab toponym (*qantarah* = bridge) attests to the presence of a Roman bridge, and then continued along the Platani. The second branch instead headed towards the Campofranco

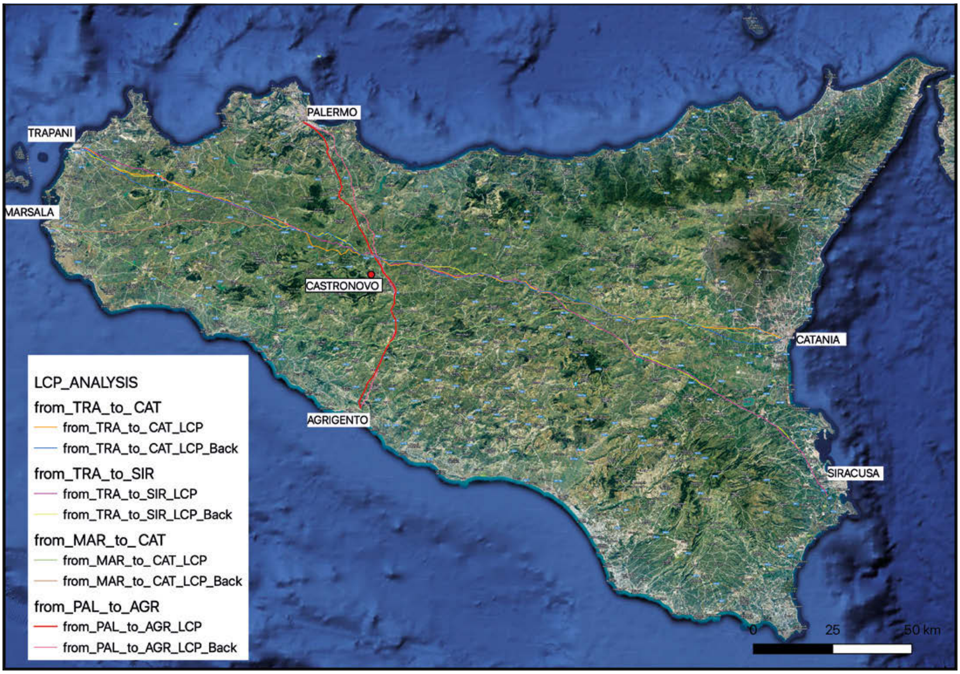



Fig. 1 – LCPA on satellite image (Google Earth).

bridge, before rejoining the Platani at Villaggio Faina. From here, the itinerary continued following the course of the river until it reached the *statio Comicianis*, which can be located using the toponym Comicia, near the current crossroads for Cammarata. The distance of 24 miles from the previous *statio* would coincide perfectly following the route that passes through the Campofranco bridge.

The following *statio Petrine*, which can be located near the current Casale San Pietro, in the Castronovo di Sicilia area (Giustolisi 1999, 30), is actually 5 miles away, only one more further than what is described in the *Itinerarium*. After the *statio Petrine* the interpretations of Uggeri and Stangati differ. Uggeri claims that the itinerary veered W continuing along the route of the older via Aurelia, and then reached Corleone before turning N again to head towards Palermo. This deviation would be testified by the only milestone now known with certainty in Sicily, found in 1954 near Corleone. However, this itinerary would not coincide with the distances reported in the *Itinerarium Antonini*.

Stangati believes that this path is the oldest of two routes that could lead from Castronovo to Palermo, probably replaced as early as the first century BCE (Stangati 2013, 41). In support of this hypothesis, Stangati reports the distance from the *statio Petrine* to Palermo in the *Itinerarium* (48 miles, which would differ greatly from the real 60 miles of the route passing through Corleone) and the difficulty in identifying the *statio Pirama*. Stangati therefore believes that the *Itinerarium* describes a second, later route, which from the *statio Petrine* continued in a northerly direction, passing near the current Vicari and arriving at the current Fondaco Tavolacci, where the *statio Pirama* could be located (24 miles from *Petrine*, only one mile further than described in the *Itinerarium*), heading then towards the bridge and the Roman baths of Cefalà Diana, finally passing through the Misilmeri bridge and arriving in Palermo (another 23 real miles from the hypothetical *Pirama*, in this case one mile less than the *Itinerarium*).

## 3. Al-Idrisi: the Book of Roger, Fourth Climate - Second Compartment - The Islands

The second written source analysed is the *Nuzhat al-mushtàq fi ikhtiràq al-afàq*, better known as the Book of Roger. The author, al-Idrisi, was born in 1099 probably in Sicily (Amara, Nef 2001), where he later died between 1164 and 1166. He was commissioned by Roger II to write a text that included the entire geographical knowledge of the era. The work was published in Palermo in 1154 following the Ptolemaic tradition; it is divided into 7 climates, each one divided in turn into 10 compartments. Sicily is located in the Fourth Climate - Second Compartment - The Islands. In the central part of the writings concerning Sicily, al-Idrisi mentions Castronovo with the Arabic name of *Qasr nûbû*, listing several distances that separate it from other places located in the central area of the island.

According to al-Idrisi Castronovo is about 10 miles from Cammarata, 12 from Prizzi, 20 from Corleone, 10 from Raia and 24 from Sutera. At the time of al-Idrisi, the Sicilian mile must have had a length between the Roman one from which it derived equal to 1,478.50 m, and that recognized in 1877 by the *Regio Decreto No. 3836*, equal to 1,486.6437 m. The difference between the two is only 0.54% and for this reason the value of the Roman mile was used in the analyses carried out, as Stangati did in his research (Stangati 2020, 18-19). As we will see in detail later, most of these distances are different, especially the arrangement of Raia. Raia, whose toponym is still preserved, has been identified with a farmhouse, located 4.5 km NW of Prizzi. Furthermore, Raia turns out to be much closer to Prizzi than to Corleone, compared to what al-Idrisi seems to indicate. Consequently, even the distances between Raia and Castronovo and between Prizzi and Raia cannot be equal, as indicated by al-Idrisi, since Prizzi is on the road between Castronovo and Raia.

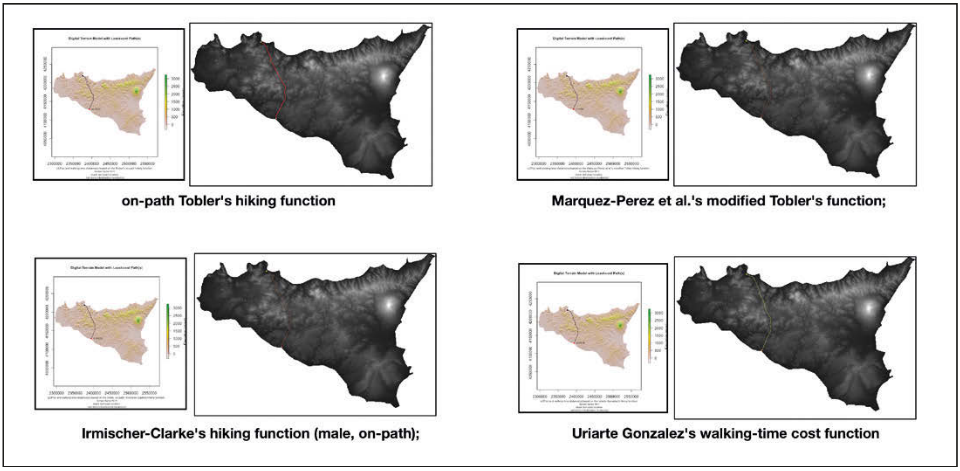



Fig. 2 – Results of the different LCPA functions tested.

## 4. Least Cost Path Analysis

The Least Cost Path Analysis was carried out using "movecost", a QGIS plugin (https://github.com/enzococca/movecostTOqgis) developed by E. Cocca (2022) based on the algorithms elaborated by G. Alberti for the R software (Alberti 2019). The plugin offers the possibility to choose which function to use for the cost calculation, from a list of 23 available functions (for a list of the ones most used in the archaeological field see Herzog 2020, 337, Tab. 18.2). For this research, different functions were tested: Marquez-Perez *et al.* modified Tobler's function (Márquez-Pérez *et al.* 2017); Irmischer-Clarke's hiking function, male, on-path (Irmischer, Clarke 2017); Uriarte Gonzalez's walking-time cost function (Chapa Brunt *et al.* 2008) (Fig. 2) before deciding to use the on-path Tobler's hiking function (Tobler 1993). The choice was motivated by the minimal differences with the other functions, as well as the fact that this function is currently the most used for LCPA in the archaeological studies (Herzog 2010, 376). The plugin also allows you to automatically download the DTM of the area of interest obtained from the NASA Shuttle Radar Topography Mission (SRTM GL1, 30 m), which is what was used during the analysis. The comparison between the results of the LCPA and the historical road network was mediated by the use of the CAD images, relating to the reconstruction of the Roman and Arab-Norman road network, elaborated by Stangati (2012, 2013).

The LCPA was elaborated on two levels: at a regional level, to analyse the distance between the Castronovo area with the least cost paths which

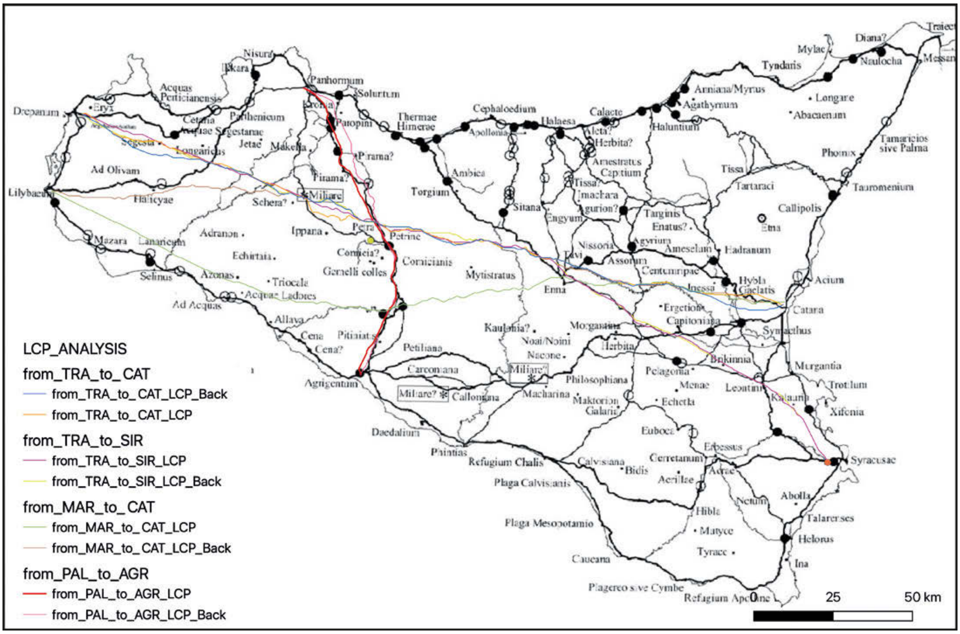



Fig. 3 – LCPA results overlapping the Roman road network map elaborated by Stangati 2007, 226.

unite the island from N to S and from E to W.; and at a local scale, to compare the data of the distances from Castronovo expressed by al-Idrisi with the paths obtained through the LCP algorithms. Regarding the regional analysis, Palermo and Agrigento were therefore used as starting and finishing points for the NS direction, while Trapani, Marsala, Catania and Syracuse were used for the EW direction (Fig. 3). For each link, the plugin highlights two distinct results, the outward path and the return one which obviously can differ, considering that the slope sections that are favourable in one direction might not be as favourable in the opposite direction.

Along the NS route from Palermo to Agrigento, it should be noted that the outward stretch differs from the return stretch in particular in the first half (from Palermo to Lercara Friddi, spacing a maximum of about 5 km near Villafrati) and in the final stretch (from Aragona to Agrigento, with a maximum distance of about 1.5 km). In the central section however, the two routes find a much higher correspondence, perfectly coinciding for a substantial part of it. The reason for this overlap is the presence of the Valle del Platani which is the best route in both directions.

The result of the LCPA between Palermo and Agrigento passes at a minimum distance of approx. 3.4 km from the centre of the current municipality


**DISTANCES FROM PETRINE**

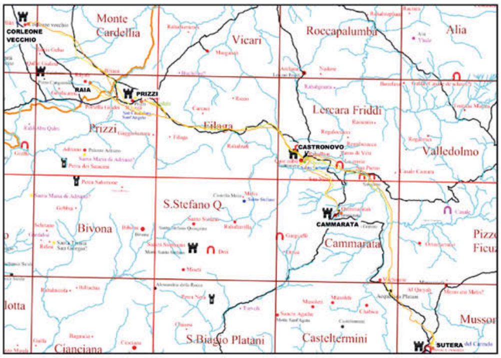
| | Itinerarium Antonini | Uggeri | LCP |
|---|---|---|---|
| Agrigentum | 37 miles | 39 miles | 31, miles |
| Pitinianis | 28 miles | 29 miles | 22,3 miles |
| Comitianis | 4 miles | 5 miles | 4,2 miles |
| Pirama | 24 miles | X | 16 - 23,8 miles |
| Panormo | 48 miles | 60 miles | 41 miles |
| Agrigentum To Panormo | 85 miles | 99 miles | 72 miles |

Fig. 4 – Comparison of the LCPA distances with the *Itinerarium Antonini* and the path proposed by Uggeri, on a map elaborated by Stangati 2007, 226.

of Castronovo and only 885 m from the Casale di San Pietro. Regarding the analysis of the EW paths, first of all it should be highlighted how the results of the Trapani-Catania and Trapani-Syracuse routes, in both directions, and Catania-Marsala tend to coincide in the central section from Corleone to Enna. All these routes pass just at 5.5 km from the centre of Castronovo, while from Casale San Pietro the minimum distance is about 4.2 km.

What is evident is the proximity of Castronovo to the area where the NS least cost paths intersect with almost all of the EW least cost paths. Secondly, a strong correspondence emerges between the road system of the Roman age and the least cost path between Palermo and Agrigento, which in some points seems to follow the sections described by the *Itinerarium Antonini*, according to the path suggested by Stangati (Fig. 4). The next phase of LCPA focused on a smaller scale, to compare the routes cited by al-Idrisi linking Castronovo to Cammarata, Prizzi, Corleone, Raia and Sutera (Fig. 5). Starting to analyse the path towards Cammarata, one immediately notices that the distance expressed by al-Idrisi is almost double that what emerged from the LCPA. In this case, Stangati also argues that the Arab geographer’s distance is wrong, but only by two miles (Stangati 2010, 106).

Surely the difference between al-Idrisi/Stangati and what is expressed by the LCPA is determined by a rather decisive physical factor: the passage of the Platani river. During the Arab-Norman era, the only known crossing of the river in this area is the *Saraceno* bridge, located approx. 4.5 km E of Castronovo, near Casale San Pietro, of which only toponymic evidence remains.




**DISTANCES FROM CASTRONOVO**

| | al-Idrisi | Stangati | LCP | LCP_Back |
|---|---|---|---|---|
| Cammarata | 10 miglia | ca. 8 miglia | 5,3 miglia | 5,1 miglia |
| Prizzi | 12 miglia | ca. 15 miglia | 11,7 miglia | 12 miglia |
| Corleone | 20 miglia | | 21,1 miglia | 21,3 miglia |
| Raia | 10 miglia | ca. 18 miglia | 15,3 miglia | 15,6 miglia |
| Sutera | 24 miglia | | 17,11 miglia | 16,9 miglia |

Fig. 5 – Comparison of the LCPA distances with the al-Idrisi path and the distances proposed by Stangati, on a background map elaborated by Stangati 2013, Tab. 1.

Therefore, analysing a path that from Castronovo heads to Cammarata crossing the river near the toponym *Saraceno*, we approximately reach the distance of 8 miles proposed by Stangati. Analysing the path towards Prizzi, the LCPA highlighted a value almost identical to that expressed by al-Idrisi. By superimposing the LCPA on various maps, it is evident how, in this case, the least cost route corresponds quite faithfully to the road network of the Roman era which headed W from Castronovo. For this reason, it is therefore possible to consider Stangati's calculation incorrect, which exceeds by 3 miles, and highlight how, in this case, the distance proposed by the Arab geographer corresponds to the LCP. The same thing happens for the route to Corleone. Also in this case the LCPA's results closely follow the historical road network while the calculated distance is just over a mile greater than the one expressed by al-Idrisi, which also in this case seems to be quite similar. However, the distance that the Arab geographer describes for the hamlet of Raia is much different, positioning it 10 miles W of Castronovo, despite the fact that the hamlet is located a few miles beyond Prizzi which, as we have seen, is already at a distance of 12 miles. The results of the LCPA give us values of 15.3 miles and 15.6 miles to reach Raia, which would seem more correct than the 18 miles calculated by Stangati.

The distance from Castronovo to Sutera is also different, which al-Idrisi calculates as 24 miles. According to the LCP analyses, the least cost routes, in both directions, are around 17 miles and, considering that the results of the analysis follow quite faithfully the stretch of Roman road system which connected Castronovo to Casale San Pietro and from here headed to S towards Agrigento, it is possible to argue that the distance of the least cost stretches is, in this case, quite reliable.

## 5. Discussion

The LCPA have shown that al-Idrisi appears to be quite accurate regarding the western stretch Castronovo-Prizzi-Corleone, while he is not as accurate regarding the southern stretch towards Cammarata and then Sutera. Wishing to speculate on these few data, it is possible to hypothesise that the Arab geographer actually travelled from Castronovo to Corleone (or in the opposite direction), probably stopping at Prizzi, which is halfway between the two; while he had only indirect knowledge of the road system that from Castronovo headed E towards Casale San Pietro where it crossed the Platani river and then headed SW towards Cammarata or, following the river, S towards Sutera. If we wanted to look for further clues to support this hypothesis, it could be highlighted how both Corleone, Prizzi (Stangati 2010, 96), and to a lesser extent Castronovo (Stangati 2010, 98) are described in sufficient detail, while Sutera is only mentioned without any description.

In contrast to this hypothesis, we certainly have the wrong location of Raia which would seem to testify to an indirect knowledge of the farmhouse which, although not exactly on the road between Prizzi and Corleone, must have been only a little further than a mile away from it. On the other hand, the description of Cammarata is more dubious: although it seems similar to those of Prizzi and Corleone, it concentrates mainly on the surrounding area, citing only the castle but without mentioning any springs (such as in Prizzi) or any running water (such as in Castronovo, Corleone and again Prizzi), despite the town being surrounded by two tributaries of the Platani. It is currently impossible to know whether this oversight is accidental or due to an indirect knowledge of the town, but not of the surrounding area, which in any case is visible from Castronovo.

## 6. Conclusion

In conclusion, it is evident that both the analysis of traditional written sources and LCP analysis emphasise the geographical importance of Castronovo along the NS axis, which runs from Palermo to Agrigento, and the route that connected the main coastal centres on the eastern and western shores of the island. Furthermore, the Castronovo area has undergone a series of transformations that have partially modified its roadways throughout historical periods. The initial road network in this area dates back to the phase of Roman conquest (milestone of Corleone). In the imperial age, the *Itinerarium Antonini* describes a second road system that takes advantage of the natural corridor of the Platani valley to connect Palermo to Agrigento, continuing no longer W but N of Casale San Pietro (*statio Petrine*), quite faithfully tracing the least cost path between the two towns. Contrarily, during the Arab-Norman age, the primary road network appears to have been the EW axis, to the detriment of the NS path which continued northwards from Casale San Pietro, which seems to have been completely forgotten.

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ABSTRACT

The area of Castronovo di Sicilia was analysed by integrating different methodologies. In terms of the road network, it was decided to compare information from traditional written sources, such as the Itinerarium Antonini and texts from the Arab geographer al-Idrisi, with the results of the Least-Cost Path Analysis (LCPA) conducted using the QGIS plugin 'movecost'. The primary objective of this analysis was to evaluate how the centrality of the Castronovo area was determined by environmental factors that made it easily accessible along the main long-distance routes connecting the island. At the same time, the analysis aimed to highlight similarities and differences between the written sources and the LCPA results.

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# "ARCHAEOLOGIS" A QGIS PLUGIN FOR ARCHAEOLOGICAL SPATIAL ANALYSIS

## 1. Introduction

ArchaeoloGIS is a QGIS plugin for very basic archaeological spatial analysis. It was inspired by the accurate studies in geography, methodology and digital humanities made by the author during the years of his participation in the ERC project PAThs. The Archaeological Atlas of the Coptic Literature (https://atlas.paths-erc.eu). The first steps were taken from the studies of the road network named MOvEIT (https://paths-erc.eu/moveit/, Bogdani 2023). The coding phase started in the winter of 2021 and the validation on the practical applications presented below were carried out during the spring of the next year. The plugin is GPL-3.0 licensed and can be freely installed from the official repository (https://github.com/archeorosati/archaeoloGIS). It is developed as a QGIS Processing Toolbox script, it is still in beta version and suggestions and questions from the community are welcomed. At present, it consists of a unique script named *Tabula Peutingeriana* after the famous imperial Roman map, able to output points at a regular, fixed distance of a Roman mile along a path or network of paths. It can be used to position virtual milestones along an already provided road network, eventually helping to find the location of original ones, by counting the Roman miles from a given starting point.

It can be used to test whether the reconstruction of the road network corresponds to the distances reported in ancient sources such as the *Tabula Peutingeriana*, *Itinerarium Antonini*, epigraphic sources, travelogues, etc. The plugin is a simplified, non parametric version of the native points along geometry QGIS algorithm. Given a correct road-network, a prerequisite that the plugin can not help to build, it could be used to place archaeological sites found along roads i.e *balnea*, mail services, horse-exchange stations, *termopolia*, *villae* and to find correspondence with place names related to the counting of miles from a major city.

## 2. Methodology

### 2.1 *The study of the* Tabula Peutingeriana *in the East Rome hinterland and the metrological issue*

The *Tabula Peutingeriana* is a complex document. The name of the scroll derives from the name of the humanist Konrad Peutinger, who discovered it in the 16th century. It is a 13th century mediaeval copy of an original Roman

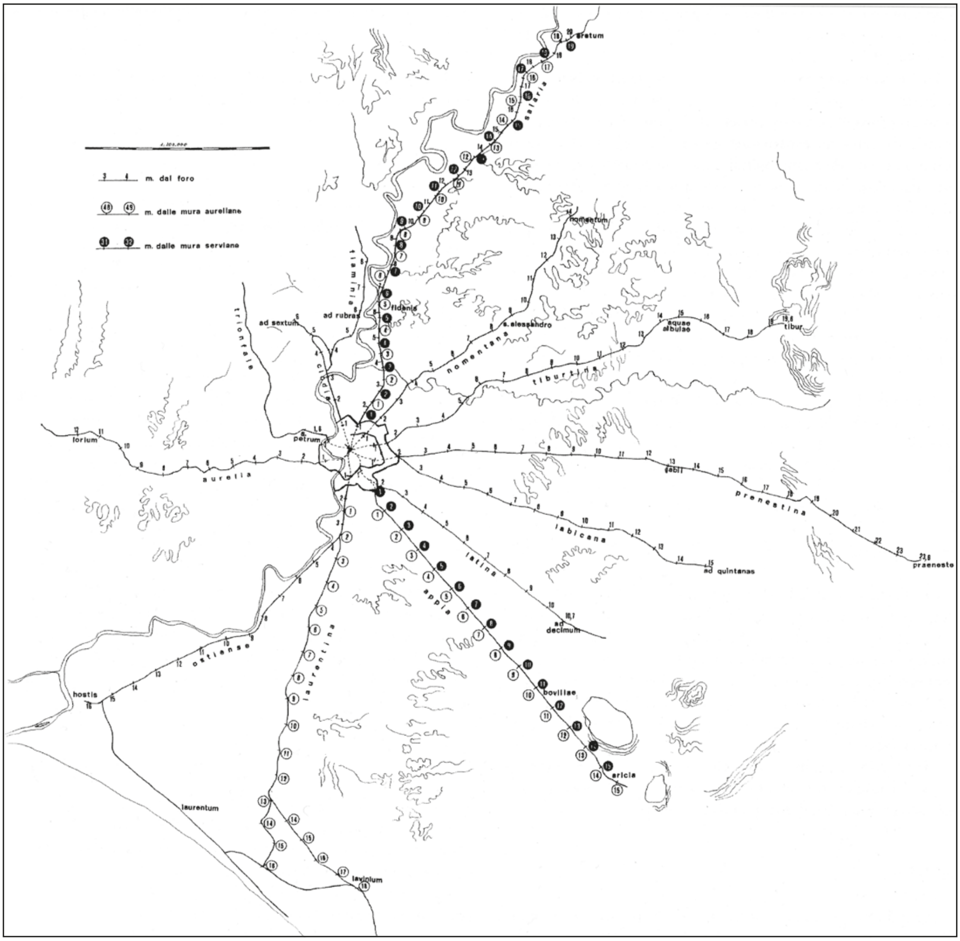


Fig. 1 – The ancient road network around Rome as reported by the *Tabula Peutingeriana* (from Passigli 1999, fig. 1).

map mainly compiled in the 3rd century CE (Diederich 2021, 374-375). The surviving copy of the map was created by in Colmar, Eastern France, in 1265. The *Tabula* is a painted parchment scroll, measuring 0,34 m high and 6,75 m long, divided into eleven sections (Rathmann 2018). The map shows the entire ancient Roman road network from Britain to Mesopotamia, including North Africa and Arabia, connected to the road networks of the other empires of Persia within India. The main bibliographical resources for the study of this exceptional source are Diedrich's agile work (Diederich 2021) and Talbert's fundamental volume (Talbert 2010).

The script being presented here was inspired by an article published by S. Passigli (1999), which reconstructed the road network within a radius of 26 Roman miles from Rome (Fig. 1). The paper applied the extensive metrology studies by G. Radke based on the ancient authors' texts, reconstructing the length of the Roman mile (*milius*) in 1481.5 m (Radke 1981, 64-66), relying uniquely on ancient sources. One of the most useful contributions on Roman metrology is the one published by M.E. Alberti (2000), fixing the length of the Roman *milius* in 1480.0 m. Moreover, field studies conducted between the 35th and 38th miles of the *via Valeria* have allowed many scholars to confirm this by measuring the distance between these milestones in 1480 m (Borsari 1890; Crainz, Giuliani 1985; Mari 2004; Buonocore 2004; Piraino 2004; Mari, Cappelli 2014).

## 3. Case study

In the next paragraphs, a case study based on the research of the ancient road system in the area around Rome is shown. The research is founded on a comparison between the *Tabula Peutingeriana* (hereafter TB) and the *Itinerarium Antonini* (hereafter IA) along the *via Valeria* from Rome to *Alba Fucens*.

### 3.1 *The road from Rome to Alba in the* Tabula Peutingeriana

On the *Tabula Peutingeriana*, *Tibur* can be reached from Rome by two different branches: 1) Rome-Nomento (13 *milia*)-*Tiburi* (10 *milia*) and 2) Rome-*ad Aqua Albulas* (16 *milia*). The second branch does not seem to cross the Anio river to Tibur, according to the map. This is because the road network between Rome and *Sublacio* in the TP crosses the *Tibur* by the Nomentana road and not by the *Tiburtina Valeria*, which is the direct and easiest connection. As Fig. 3 shows, the red segment between *Aquae Albulae* and *Tibur* stops near the Aniene river. With the exception of S. Passigli (1999) (Fig. 1), there are no publications of maps with miliaria for this section of the road. After this, the route to the colony of *Carseoli* continues beyond *Tibur: Tibori-Varie* (8 *milia*)-*Lamnas* (5 *milia*)-*Carsulis* (10 *milia*).

The first section of the *via Valeria*, from *Tibori* to *Ad Lamnas*, was largely studied and surveyed by C.F. Giuliani (1964) and published in 1964 in the carta 2 of its *Forma Italiae*. In this publication there is no mileage counting reported. The second section going from *Lamnas* to *Carsulis* was studied by C.F. Giuliani and F. Crainz and was published in 1985 in their tav. 8 (Crainz, Giuliani 1985), where the position of certain milestones found by L. Borsari (1890) was recorded. This study was later confirmed by the excavations of Z. Mari (Mari, Cappelli 2014). The last section of this road is the most debated one. It connects the colony of *Carsulis* with the Marsica territory on a mountain route that climbs over a thousand-meter pass to glide towards the heart of the


Fig. 2 – The *Tabula Peutingeriana* and the “Road to Alba”.

Anio valley, at *Sublacium*: *Carseoli-in mons Grani* (7 *milia*)-*in mons Carbonario* (*5 milia*)-*ad Vignas* (*5 milia*)- *Sublacium* (7 *milia*)-Marrubio-Alba (13 *milia*).

There is not a direct connection between *Carseoli* and *Alba Fucens* in the TP, as we might have expected, and we can not tell if this is an error by the mediaeval copyist. The direct route between the city of *Sublacium* and *Marrubium* could exceed 40 *milia*, in a difficult, but not impossible (at least in summer), mountainous area often over 1,200 m above sea level. Sebastiani del Grande (2020) has reconstructed a mountainous route connecting *Carseoli* and Alba, along which there are some shrines and ancient resting places, as confirmed by surveys by the author of this paper (Fig. 5). This hypothesis is shown in Fig. 3, completed with road traces and miles indication. The dataset created for this project has been published as open data and distributed with CC BY-NC-SA 4.0 Licence (https://doi.org/10.5281/zenodo.7827642).

### 3.2 *The road from Rome to Alba in the* Itinerarium Antonini

The *Itinierarium Antonini* route lists the following places:

[4] *Valeria*
[5] *Ab Urbe Hadriae usque m(ilia).p(assu)m. CXLVIII sic*
309 [1] *Tiburi* m.pm..*XX*
[2] *Carsiolos m. pm. XXII*
[3] *Alba Tucentia* m.pm. *XXV* (Parthey, Pinder 1848, 146-147).

The route reconstructed from the list of places and miles is much more linear and direct than the one represented in the TP. The *via Valeria* starts possibly from the *Milius Aureus*, the *Umbellicus*, placed at the centre of Rome, S of the arch of Septimius Severus. After *Tibur*, it is easy to count

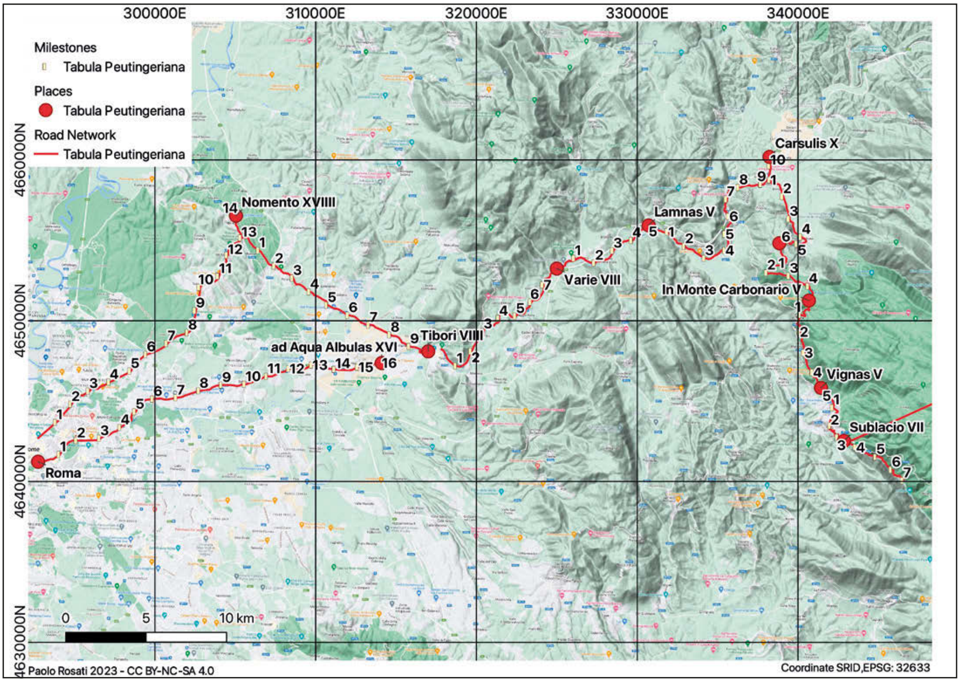


Fig. 3 – The map of the reconstructed road network between *Roma* and *Sublacio* from the study of the *Tabula Peutingeriana* (miles, places and network confirmed using ArchaeoloGIS).

the mileage to *Carsiolos*, the miles corresponding exactly with the 22 *milia* reported in the TP. Then the road goes from *Carsiolos* to *Alba Tucentia* in 25 *milia*, following the original path of the *via Valeria*, dated from the last years of the 4th century BCE (Piraino 2004).

## 4. Results

A piece of evidence recovered by this study is related to the exact measurement of the distance between the *Milius Aureus*, near the arch of Septimius Severus and the so-called Arcus of Gallienus, the ancient *Porta Esquilina* from which most Roman roads heading E started. This segment, as reconstructed on the ancient road system available in R. Lanciani’s *Forma Urbis Romae* (Lanciani 1894) and the SITAR database (Serlorenzi, D’Andrea, Montalbano 2021), measures exactly 1480 m. Thus, the position of the ancient milestones along the eastern roads coincides whether one starts counting from the *Milius Aureus* (*Itinerarium Antonini*) or from the *Porta Esquilina* (*Tabula Peutingeriana*). The first mile of the *via Tiburtina* of the *Itinerarium*

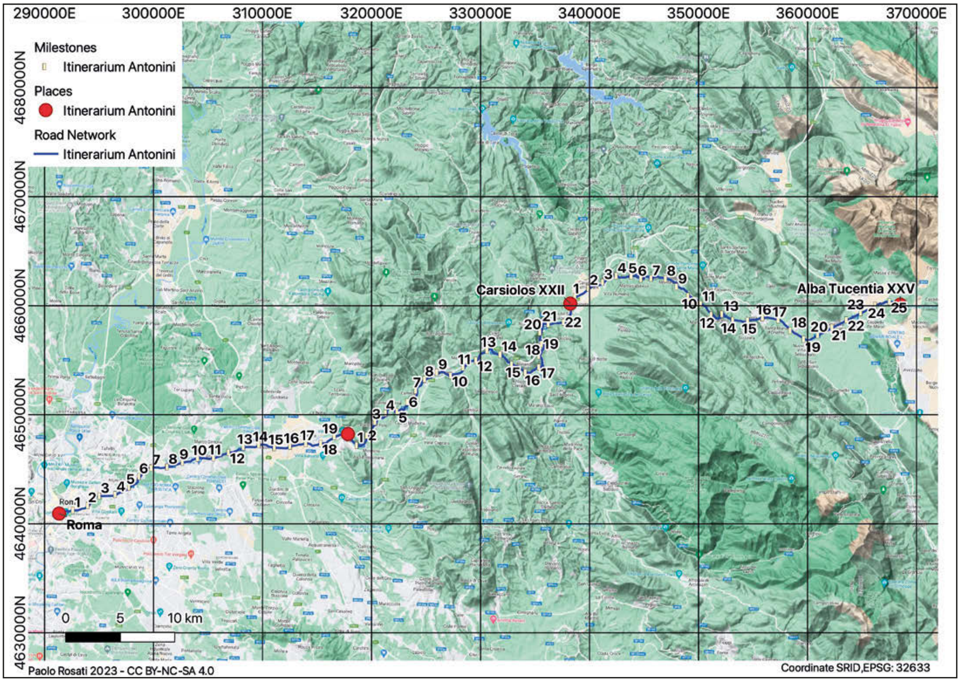


Fig. 4 – The map of the reconstructed road network between *Roma* and *Alba Tucentia* as in the *Itinerarium Antonini*, miles, places and network confirmed using ArchaeoloGIS.

*Antonini* corresponds to the starting point of the mile count of the same road in the *Tabula Peutingeriana*, and so on.

Despite this difference, the measures on the milestones are based on the departure from the *Umbilicus Urbis Romae*, the *Milius Aureus*. This is archaeologically testified by the 35th and the 36th milestones preserved in the Museo della Civiltà Contadina della Valle dell'Aniene in Roviano and the 37th presently at the centre of the Arsoli main square. Secondly, the plugin can be useful to demonstrate the reliability of a road network, i.e. whether the count of the miles of the road system archaeologically reconstructed corresponds with the mileage of the TP or IA. Another possible plugin usage could be to recover the original position of actual decontextualised milestones, preserved in museums or elsewhere. Moreover, when a *statio* or an important infrastructure near a major road is found by archaeological excavation, ArchaeoloGIS can help to recognise the original name available on the *Tabula Peutingeriana* or, the other way round, to search for archaeological evidence in an area where these emergencies are witnessed on the map but not yet located on the ground.

Fig. 5 – Road to *Sublacio* from *Carsulis*, an image of the archaeological evidence of the road mapped in the *Tabula Peutingeriana* (P. Rosati 2021).

## 5. Conclusions

The plugin and the methodology analysed in this paper are simple and intuitive and could be of some help for the field research. These are suitable tools to use with already available road networks for, such as the one provided by DARE: The Digital Map of Roman Empire (https://dh.gu.se/dare/). These tools can also be used to test new or alternative hypotheses for the reconstruction of Roman road traces, on the basis of literary, archaeological or topological studies, or a combination of them. The next steps of development will involve the implementation of other ancient units of linear measurements, such as Hellenistic *stadia*, Persian *parasangae*, etc.

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ABSTRACT

The purpose of the paper is to introduce a QGIS plugin named ArcheoloGIS. It is developed in PYQGIS and tested by the community of Una Quantum Inc. (Italy). It consists of a decorator algorithm named *Tabula Peutingeriana*, that outputs points at a regular distance, every one Roman mile, along a given path. The article shows its use, the construction of a possible dataset and its evolution, as well as a case study of its application.

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# BACKWARD ENGINEERING HISTORICAL MAPS: THE UPDATE OF THE OPEN HYDROGRAPHY DATASET OF NAPOLEONIC CARTOGRAPHY

## 1. Introduction

This article is the natural continuation of other publications issued in the context of the research activities of the LAD: Laboratory of Digital Archaeology at Sapienza concerning the *Carte topographique de l'Égypte* edited by Pierre Jacotin (Jacotin 1818; Godlewska 1988), in the context of the French Campaign in Egypt and Syria under the command of Napoleon Bonaparte, at the turn of the 18th and 19th centuries. The LAD was established in 2021 at Sapienza University of Rome to collect several research projects sharing a strong interest in the application and development of digital tools and methods to the archaeological domain. A particular attention is paid to the application of network and web technologies to the management, analysis and dissemination of the archaeological data and processes in an open and collaborative way. Following the directions traced by the Open Science directives, LAD fosters the adoption of open software, hardware and methodologies in the daily archaeological practice, the creation and sharing and publication of open archaeological data. Specific software tools have been created and made available to the community to reach this end (Bogdani 2022a) and a continuous effort is spent toward a greater awareness of younger scholars and colleagues through practical laboratories dedicated to Archaeological Information Systems and Databases, GIS platforms and new formats, standards, and technologies for the publication of the archaeological record.

One of the LAD's projects was the digitisation of the Napoleonic map of Egypt, an activity that started in 2019 and that was accelerated by the outbreak of the Covid pandemic that put a harsh stop to the other field activities. The methodological aspects of the georeferencing process have already been published in 2019 (D'Erasmo 2019, 1-9). More recently, the orthorectified map has been published as an open access tiled web map service (Bogdani 2022b) and the same is true for rich vector datasets that have been acquired from the document with a very patient digitising work (Bogdani *et al.* 2022). The resulting data set has been published as open access on the Zenodo repository (Bogdani 2022c), and a demonstrative and interactive version has been made freely available online as vector web tiles (https://lab-archeologia-digitale.github.io/jacotin-1828/).

A special focus has been put on the hydrographic network, an element that has undergone many changes in the last two centuries determining, in turn, thorough changes in the Egyptian landscape. The Nile and its branches have been the indispensable natural prerequisite for the birth of the Egyptian civilisation and have continued to determine its economic, population, and cultural landscape throughout the millennia. The digital documentation of the pre-modern situation documented in the Napoleonic map is of great interest to specialists of archaeology and history of different chronologies.

Tightly related to the river is the population and the settlement network, that was the second theme under study. Thanks to the renewed interest of scholarly research in historical gazetteers, it was possible to offer a major aperture towards the community by trying, through different methodologies, to link our digitised 18th century Egyptian places to other records of gazetteers, both historical and current. It is not an easy task to deal with anthropic landscapes that have undergone radical changes, and we have tried not to conceal the gaps produced by the missing data but to fully document our difficulties in the hope that others in the future will do better than we did. Finally, this short contribution is aimed at sharing our latest attempt to expand the hydrographic theme by trying to provide outbound links and to reproduce the LOD (Linked Open Data) approach experimented with the settlement network.

J.B.

## 2. Egypt: an ever-changing landscape

The question about "how can an ancient landscape be reconstructed?" is increasingly being answered by Landscape Archaeology. By means of a wide range of tools such as the study of written sources, historical maps, archaeological evidence, geoarchaeological and paleoenvironmental studies, this branch of the discipline attempts to offer a broad overview of ancient landscapes regardless of their location. Among the various tools mentioned, one of the most widely used to work around the obstacles imposed by the changing landscape in times is the use of historical cartography. As far as Egypt is concerned, a valuable cartographic document that can provide a precious aid to the study of the ancient landscape is the *Carte topographique de l'Égypte*.

From the Prehistory through the Pharaonic era to Hellenistic, Roman, Medieval, and Modern times, the landscape of Egypt has changed a lot determining different topographical organisation of the country and significantly transforming settlement, road, and hydrographic networks (Wilson 2012; Cooper 2014; Ghiringhelli 2017, 2021). New villages and towns were founded from one age to the next which over time expanded, were either abandoned or relocated. The marshy areas that characterised large portions of the landscape were reclaimed, and canals were built or restored either to


Fig. 1 – Satellite images from Google Earth Engine of the Wādī al-Naṭrūn in 1984 (a), in 2004 (b) and in 2020 (c).

improve connections between places or to facilitate agricultural practices. There is little archaeological evidence left of the many interventions, and both written sources and historical cartography provide a fundamental source of information. As far as the country's hydrographic network is concerned, this continuous cycle of transformation peaked with the construction of the Aswān Dams, both the Low Dam, built at the end of 1800s, and the High Dam, active since 1970. This action allowed large portions of desert areas to be irrigated, and inevitably produced a major change in the landscape.

An example is the area of Wādī al-Naṭrūn, a desert depression located 90 km NW of Cairo that was the location of several monastic complexes since 360 CE, the time to which the foundation of the Monastery of St. Macarius dates (https://atlas.paths-erc.eu/places/208). The area is now surrounded by cultivations that effectively alter the understanding of the ancient landscape in which the archaeological evidence of the monastic complexes was framed (Fig. 1). Other examples can be added, originating from the construction of the Aswān Dam, such as coastal erosion and the flooding of the islands located along the course of the Nile (Hillier *et al.* 2006; Graham 2010; Badawy 2021). The case of the island of Philae is emblematic: its temples endangered by the construction of the Lower Dam were dismantled and reassembled on the nearby island of Agilkia. These are only a few famous events that have occurred in Egypt over the centuries and that have played a part in the evolution of an ever-changing landscape, heightening the demand for useful tools to study it.

D.D.E.

## 3. Towards a LOD infrastructure for the study of ancient Egyptian hydrography

The LAD team has been working on the digitisation of the Napoleonic map by georeferencing it and by vectorising the networks regarding

Fig. 2 – Screenshot showing 3D visualisation of the hydrography dataset of Napoleonic cartography v. 3.5. (from https://lab-archeologia-digitale.github.io/jacotin-1828/).

hydrography and settlements (D'Erasmo 2019; Bogdani *et al.* 2022). However, an 18th century cartography is a static document, even if it has been digitised, and moreover not all the topographical units represented within it are to be considered ancient (Fig. 2). Indeed, several topographic and hydrographic elements represented in the *Carte topographique* existed in different periods of Egyptian history. For these reasons, although the Napoleonic map is a valuable document for observing the landscape of Egypt before the great changes of the modern and contemporary ages, it remains a snapshot. Behind the place names and hydronyms catalogued by French *savants* there are millennia of history bearing witness to geopolitical, commercial, and agricultural dynamics of past times. For these reasons, the LAD team decided to make an upgrade of the original dataset resulting from the digitisation of Napoleonic cartography, starting with the hydrographic network. This update aims to make a quite static dataset, documenting the late 1700s, queryable by linking it to online geographic databases taking a step toward a LOD infrastructure and adding new information that help in the study of the ancient Egyptian landscape.

### 3.1 *A new dataset: the hydrographic network v. 4*

The fourth version (v. 3.5) of the Napoleonic hydrographic network dataset developed by the LAD contains few attributes (Bogdani *et al.* 2022, 83):

– unique numeric identifier (URI);
– name in French, as reported in the Napoleonic map, when available;

– type of the geographical feature, using the map of values;
– the assigned order of each element.

According to the typology of the watercourse, these attributes are linked to a specific geometry type: lines where rivers and canals are concerned, and polygons with special regard to lakes, marshlands, ponds, the branches of the Nile and the Nile itself. In version 4 of the dataset (v. 4), the aim is to link existing geometries to online databases mentioning the elements present in the Napoleonic map and expand the attribute table with information regarding the chronology of the watercourses and whether they can be navigated.

As regards the linkage of the dataset with existing online databases, it must be emphasised that in recent years, numerous international projects have created open geographical databases for the study of the ancient world. Most of these databases focus on the investigation of ancient toponymy, providing information on the evolution of place names over the centuries. More often, the entries of these databases are linked to geographical coordinates that give the precise or approximate location of places in the world. The coordinates refer to point elements or to areas, especially where the location of the place is uncertain (e.g. https://pleiades.stoa.org/places/727068). Currently, as far as Egypt is concerned, there are no open datasets that provide complex geometries related to ancient hydrography except that of the Ancient World Mapping Centre (http://awmc.unc.edu/wordpress/). However, this dataset focuses only on the Hellenistic and Roman times and is based on the vectorisation of the Barrington Atlas (Talbert 2002; http://awmc.unc.edu/wordpress/map-files/).

V. 4 will mainly be linked to databases that contain information on the toponymy of the single watercourse and not geometries mapping its course. The databases selected are Pleiades (https://pleiades.stoa.org/), Trismegistos (https://www.trismegistos.org/), and ToposText (https://topostext.org/) and they were chosen because of geographical contents about many waterways depicted in Napoleonic cartography. Another fundamental attribute for v. 4 is the chronology. Considering that the final goal of this version is to provide a queryable dataset that also gives information about the existence in times of the digitised elements, it was decided to create two numeric fields, "chrono_from" and "chrono_to", in which the chronological reference range for each vectorised element will be entered, if possible.

The hydrographic network was not only used to supply water to places but also as communication paths, and for this reason it was decided to include a last numerical field in v. 4. This information regarding the possibility of sailing or not sailing a watercourse using a numerical range from "0" to "3" where 0 equals non-navigable and 3 equals navigable. This data can


Fig. 3 – The Alexandria Canal vectorised from Napoleonic cartography.

be found from written sources or from geoarchaeological investigations, as will be seen below in paragraph §3.2 for the case of the Alexandria Canal.

To summarise, the following fields will be added to v. 4:

– the unique numeric identifier of Pleiades, when available;
– the unique numeric identifier of Trismegistos, when available;
– the unique numeric identifier of ToposText, when available;
– the date to which the watercourse is dated, when available;
– the date on which the watercourse stops flowing, when available;
– the navigability level of the waterway, when available.

### 3.2 *The case of the Alexandria and Suez Canals*

The development of v. 4 is still in progress. Nevertheless, in this paragraph specific reference will be made to two waterways of the Egyptian hydrographic network shown in Napoleonic cartography that have different histories and a different chronology and that can be good examples to describe the structure of the new dataset: the Alexandria Canal and the ancient Suez Canal. Following through the possibilities offered by these two watercourses,

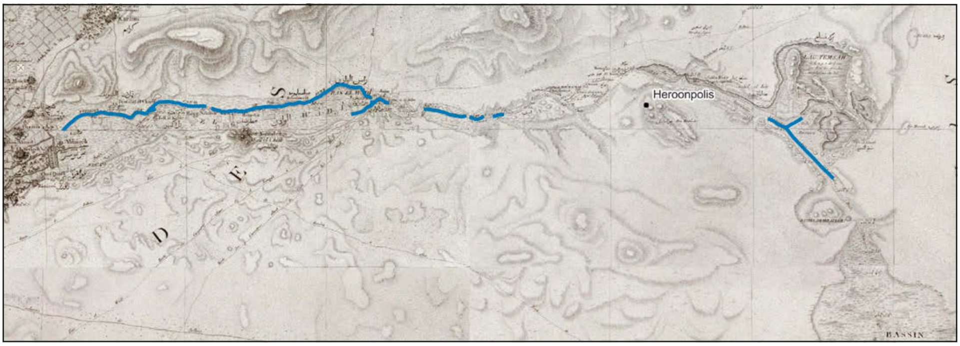


Fig. 4 – The remains of the ancient Suez Canal vectorised from Napoleonic cartography.

the implementation process from v. 3.5 to v. 4 will be outlined. In the v. 3.5, the Alexandria Canal (Fig. 3) has three attributes:

– name: Canal d'Alexandrie;
– typology: canal;
– order: 8.

The Alexandria Canal (today al-Maḥmūdiyya Canal) was built around 331 BCE to supply water to the city of Alexandria and therefore did not exist in the earliest Prehistoric and Pharaonic times. This waterway initially extended as far as the village of al-Naṣ̱ẖ al-Baḥrī, ancient Schedia, where it connected to the Canopic branch of the Nile. However, the Canopic branch dried up before the Islamic conquest of Egypt (640/641 CE), since at that time the Alexandria Canal was connected to the Bolbitine branch that replaced the Canopic in the canal's supply (Labib 2012). In addition, written sources indicate that travellers often preferred to reach Alexandria through secondary waterways leading to the city by Mareotis Lake because the canal was subject to silting. However, contrary to this, recent geoarchaeological studies suggest that after the dissecation of the Lake Mareotis in 9th century CE the Alexandria Canal was the preferred path to reach the West coast of the Delta (Flaux *et al.* 2017, 678-680).

The goal of v. 4 will be to implement the Alexandria canal geometry record with fields containing the information outlined above and link it to databases that mention it:

– name: Canal d'Alexandrie;
– typology: canal;
– order: 8;
– pleiades_id: 727068;
– trismegistos_id: 60;

– topostext_id: 3073302WAga;
– chrono_from: -331;
– chrono_to: 2023;
– navigable: 2.

The other example is the ancient Suez Canal (Fig. 4). This waterway that connected the Egyptian delta to the Red Sea through the Wādī Ṭumīlāt was probably inaugurated at the end of the 2nd millennium BCE by Sesostris III. At that time, it was named Pharaoh's Canal and continued to be used, despite periods of abandonment and reconstruction, until the mid-eighth century CE (Kramers 2012; Redmount 1995). This channel testifies the existence of a waterway connecting Egypt and the Red Sea since the Pharaonic period. In the v. 3.5 the attributes associated with the ancient Suez Canal were:

– name: Vestiges du Canal de Suez;
– typology: canal;
– order: 11;

The v. 2.0 will report the following attributes:

– name: Vestiges du Canal de Suez;
– typology: canal;
– order: 11;
– pleiades_id: NULL;
– trismegistos_id: 54477;
– topostext_id: NULL;
– chrono_from: -1879;
– chrono_to: 760;
– navigable: 3.

Those of the Alexandria Canal and the Suez Canal are just two examples that testify to the informative potential of version 4 of the hydrographic dataset of Napoleonic cartography. Once completed, v. 4 will be an entirely innovative tool for the study of the ancient Egyptian landscape.

D.D.E.

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ABSTRACT

Since 2019, the LAD team has been working on the digitisation of the Carte topographique de l'Égypte through a GIS platform. The data contained in this historical cartography, published in the early years 1800s, play a key role in research on the ancient Egyptian landscape, yet they show a still image from the late 1700s. Taking a step towards a Linked Open Data (LOD), this paper illustrates the work of updating the already published dataset of the hydrography of Napoleonic cartography by the LAD team, to which new information useful for the study of the Ancient Egyptian landscape will also be added.

# MODELLING THE LANDSCAPE.
# FROM PREDICTION TO POSTDICTION.
# PROCEEDINGS OF THE INTERNATIONAL SESSION AT THE 7TH LANDSCAPE ARCHAEOLOGY CONFERENCE (IAȘI, 10-15 SEPTEMBER 2022)

edited by

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# MODELLING THE LANDSCAPE. FROM PREDICTION TO POSTDICTION

During the 7th edition of the Landscape Archaeology Conference (LAC 2022, online meeting), the session *Modeling the landscape. From prediction to postdiction* was held. The idea of the organizers was to allow different scholars to discuss the use of models for the study of ancient landscapes in both the "canonical" predictive mode and the more "experimental" postdictive use. But what is meant by these two terms? By the term predictive we mean all those models that have played a key and significant role in recent decades. They have been used in archaeology to handle the complexity of data. However, researchers have also used these tools to reconstruct past scenarios. Early attempts to create predictive models in archaeology focused on settlement choices and were driven by the need to manage cultural heritage (Van Leusen 1992, 2002, ch. 1.3; Van Leusen, Kamermans 2005). Today, the human-environment relationship seems the most fruitful development for obtaining new knowledge. Connectivity, resource exploitation, and long duration fit well with a predictive approach. Phenomenological experiments also look promising.

However, the set of predictivity-based approaches returns a certain degree of rigidity (Tab. 1). It is precisely this rigidity that underlies the criticism of determinism, made by more skeptical researchers against the use of models for historical reconstruction. Thus, the debate on the use of modeling is actually polarized between those who consider it a fundamental tool and those, on the other hand, who think that it generates inevitable and predictable results. The proposed session aimed to overcome this alternative toward postdictive models (Citter 2007; Brogiolo *et al.* 2012; De Guio *et al.* 2013, 2015; Arnoldus-Huyzendveld, Citter 2014; De Guio 2015; Arnoldus-Huyzendveld *et al.* 2016).

| Predictive Model | |
| --- | --- |
| Strengths | Weaknesses |
| – Manage the data set's complexity<br>– Reconstruct past scenarios too (settlement choices, heritage management, connectivity, production …) | – Certain degree of rigidity<br>– (Determinism?)<br>– Bias of available data |

Tab. 1 – Strengths and weaknesses of predictive models.

Postdiction is flexible because it starts from observed data and produces simulated scenarios by mixing different human and environmental agents.

The best-fitting scenarios return the most likely set of agents involved. This allows us to take advantage of large amount of data already produced and, at the same time, to create a rigorous theoretical and methodological discussion. Reconstructing human behavior over time is no less important than reconstructing past landscapes. On the contrary, the former has shaped the latter. However, there is a somewhat problematic aspect: currently a serious and in-depth reflection (both theoretical and methodological) on the topic of postdictive models is missing (Tab. 2).

| Predictive Model | |
|---|---|
| Strengths | Weaknesses |
| – Flexible (produces simulated scenarios by mixing several agents)<br>– Allows us to profit of the large amount of data and, at the same time, to boost a serious theoretical and methodological discussion | – It lacks a rich theoretical and methodological discussion<br>– Uncertainty of selected parameters among source data<br>– Chronological set |

Tab. 2 – Strengths and weaknesses of postdictive models.

To initiate a theoretical and methodological discussion on how to refine the use of these fundamental tools, scholars from various disciplines and backgrounds were invited to present different models used as case studies to analyze ancient natural and anthropogenic landscapes from Prehistory to Late Antiquity. In fact, regardless of the chronological span presented, through the comparison of different analytical techniques used and methodologies applied to different contexts, an attempt has been made to focus on the state of the art of the debate on the use of pre-postductive modeling for the analysis of ancient landscapes and to indicate possible ways forward.

The contributions cover a wide chronological and geographic span (Fig. 1): starting with the Prehistory of Asia (A. Kafash *et al.*) and Europe (G. Bilotti; G. Pizziolo; S. Caracausi *et al.*), continuing with the Protohistory of Italy (L. Burigana; A. Sotgia; M. Cabras *et al.*), moving to the borders of Europe in the Classical period (A. Bödöcs; V. Ria, R. Rizzo; P. Trapero Fernández), and concluding with the Middle Age, once again in Italy (C. Citter, Y. Paciotti; A. Cardone) – a country in which a *longdurée* approach is widely applied (C. Mascarello), as in the final text of this collection. From the point of view of the topics covered, however, there are many shared and overlapping points in the presented research (Fig. 2), such as resource management in the landscape (both from a productive and administrative point of view), settlement choices or connectivity between different sites. This shows how the use of models completely crosses the entire archaeological discipline and is one of its most important tools.

We hope that the publication of the papers presented in the conference session will be both a good starting point for those who want to approach

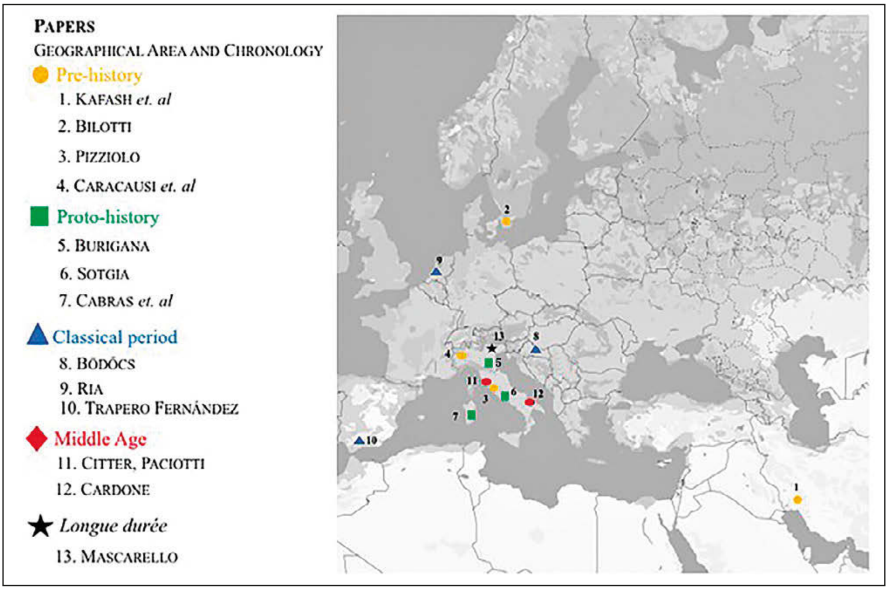


Fig. 1 – Geographical area and chronology of the papers of the session.

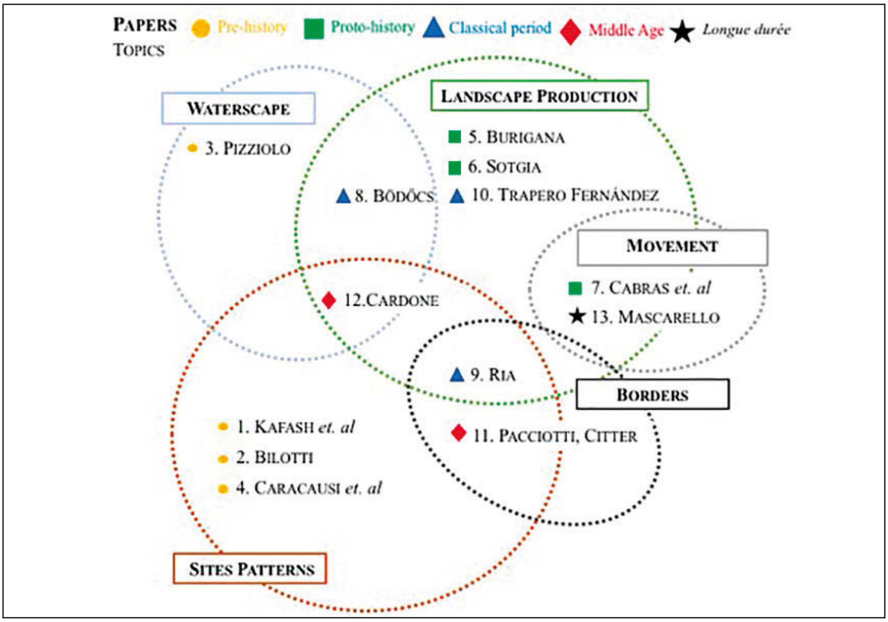


Fig. 2 – Main topics of the papers of the session.

this topic, as well as a further support for those, on the other hand, already making use of models and wanting to contribute to broaden the theoretical and methodological reflection about this very important tool of the archaeological discipline.

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# RECONSTRUCTION OF EPIPALEOLITHIC SETTLEMENT AND "CLIMATIC REFUGIA" IN THE ZAGROS MOUNTAINS DURING THE LAST GLACIAL MAXIMUM (LGM)

## 1. Introduction

The Iranian Plateau is an important geographical unit located in a key potential region for the Pleistocene population dispersals across Eurasia (Trinkaus *et al.* 2008; Heydari-Guran 2014, 2015; Vahdati Nasab, Ariamanesh 2015; Ghasidian 2019; Ghasidian *et al.* 2019; Zanolli *et al.* 2019; Heydari-Guran, Ghasidian 2020). Despite its important location and a long history of archaeological investigations, Paleolithic period on this plateau remained less explored compared to other parts of the Old World (Dennell 2009; French 2021; Shoaee *et al.* 2021). This is particularly true for the Epipaleolithic period.

Previous surveys in the Zagros Mountains resulted into the discovery of a number of Epipaleolithic sites in the different parts of the Iranian Plateau (reviewed in Shoaee *et al.* 2021). Although one might expect more intense human communities in the last Paleolithic phase, the archaeological research documented fewer Epipaleolithic sites than in the Upper Paleolithic. This might be due to the less frequent research in the Epipaleolithic period. In addition, the discovery of these sites was not the main target of Paleolithic researches. Almost all of them were the result of side-discovery of other research questions and interests for the late Pleistocene through Holocene investigations (Jayez 2021). We still do not know the dawn and demise of this period in the Iranian Plateau. The lifeways and site distribution during Epipaleolithic remained relatively unknown even in the Zagros, where our knowledge on the Paleolithic is more detailed than the other parts of the Iranian Plateau.

Ecological/eco-cultural niche models (Banks 2017; Guisan *et al.* 2017) are known as one of the most effective and practical tools to reconstruct distribution of a specific culture or hominin species and to study environmental determinants of their occurrences (Banks 2017; Benito *et al.* 2017; Yousefi *et al.* 2020a). In fact, eco-cultural niche models use occurrence data and paleoenvironmental variables to calculate probability of a specific culture or hominin species' presence in a defined geographic region (Guisan *et al.* 2017). Thus, coordinates of archaeological sites which are associated with the Epipaleolithic artefacts together with climatic data characterizing Earth climate during the LGM can be used to reconstruct a specific culture or hominin distribution during this era. This approach was frequently used to reconstruct different hominin species distribution at different geographic regions (Banks *et al.* 2011; Franklin *et al.* 2015; Benito *et al.* 2017; Yousefi, Shabani, Azarnivan 2020). The aims of this study are as follows:

– Modelling of Epipaleolithic sites distribution for the Zagros Mountains.
– Determine the most influential climatic and topographic factors in shaping Epipaleolithic site distribution.
– Identifying Epipaleolithic humans climatic refugia during the LGM.

## 2. Materials and methods

### 2.1 *Study area*

The study area in this research includes the whole Zagros Mountains (Fig. 1). These mountains were occupied by different hominin species during the Pleistocene period (Zanolli *et al.* 2019). The paper will focus on the data available on the Epipaleolithic era from Northern Zagros located in Iraqi Kurdistan to the Southern Zagros Mountains.

### 2.2 *Epipaleolithic occupations data*

To reconstruct Epipaleolithic humans distribution during the LGM in Zagros Mountains, we used coordinates of archaeological sites which are associated with the Epipaleolithic artefacts. For this reason, we conducted a literature review and assessed all related published papers. Besides, one of the authors of this manuscript (S.H. Guran) provided unpublished coordinates of the Epipaleolithic locations based on his survey into the area.

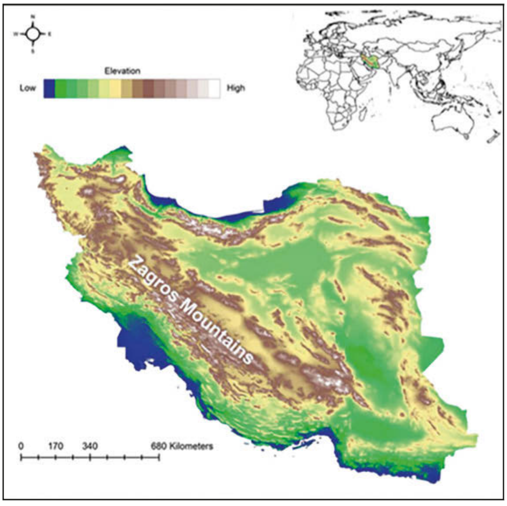


Fig. 1 – Study area, Zagros Mountains.

## 2.3 *Paleoclimate data*

Two general atmospheric circulation models (GCM), the Community Climate System Model (CCSM4) and the Model for Interdisciplinary Research on Climate (MIROC), were used to generate past climate scenarios (averaged values). Climate data from these models were used to reconstruct Epipaleolithic humans distribution.

## 2.4 *Epipaleolithic settlement modelling using ensemble approach*

To reconstruct the Epipaleolithic settlement distribution, we used five algorithms: Generalized Linear Models (GLM, Mccullagh, Nelder 1989), Generalised Additive Models (GAM, Hastie, Tibshirani 1990), Generalised Boosting Models (GBM, Ridgeway 1999), Maximum Entropy Modelling (MAXENT, Phillips *et al.* 2006), and Random Forest (RF, Breiman 2001). Then we applied an ensemble approach (Araújo, New 2007) to combine the predictions generated by different individual Species Distribution Modelling (SDMs) into a single final distribution model in R software version 3.3.3 (R Core Team, 2017). Performance of the models was assessed by area under the receiver operating characteristic curve (AUC) (Fielding, Bell 1997). This metric is widely used in SDM studies and its values range from 0 to 1 with a value of 0.5 indicating that the performance of the model is not better than random, while values closer to 1.0 indicate better model performance (Swets 1988).

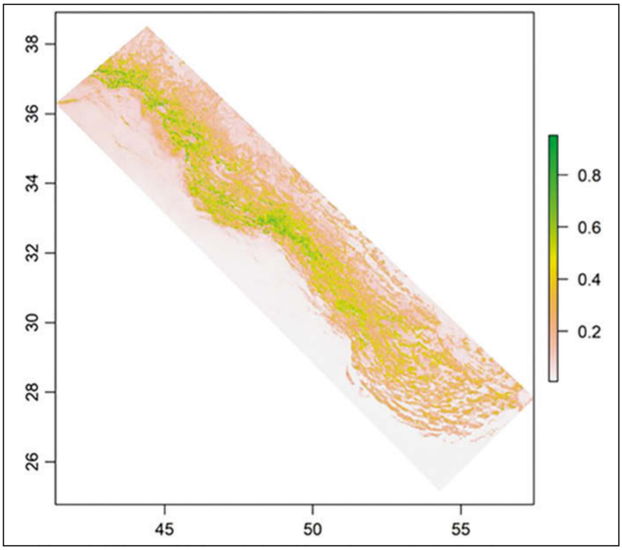


Fig. 2 – Habitat suitability model for Epipaleolithic settlement distribution in Zagros Mountains.

## 3. Results

All the models developed in this study performed well based on the AUC values. The results showed that central parts and western slopes of the Zagros Mountains were the most suitable areas for Epipaleolithic settlement during the LGM (Fig. 2). Topographic complexity was the most important variable in shaping the Epipaleolithic settlement distribution (Fig. 3) showing a positive association (Fig. 4), meaning that areas with higher topographic diversity were more suitable for Epipaleolithic communities. Annual precipitation was the second most important predictor for the distribution of Epipaleolithic humans with a positive correlation showing that areas with higher precipitation were more suitable for them. Reconstructed dispersal corridors of the Epipaleolithic humans in the Zagros Mountains are visualized in Fig. 5.

## 4. Discussion

Here we presented the reconstructed distribution and corridors of the Epipaleolithic humans in Iran. Suitable patches identified for the Epipaleolithic, generally are similar to those identified for other the Paleolithic periods of Zagros, particularly the Kermanshah region (Heydari-Guran, Ghasidian 2020; Yousefi *et al.* 2020a, 2021).

Topographic complexity, precipitation and elevation were the most important variables in shaping the Epipaleolithic settlements in the Zagros Mountains. These findings are in accordance with previous studies that identified topographic complexity as main determinant of the Paleolithic groups distribution on the Central Iranian Plateau. Elevation was identified as the most influential predictor of past distribution of the Middle Paleolithic hominin in the Kermanshah Region. Previous studies have shown that areas with higher topographic complexity in the Zagros Mountains have high mammal species (Kafash *et al.* 2021; Yousefi *et al.* 2022a). Thus, areas with higher topographic complexity and precipitation were more suitable for Epipaleolithic humans having higher biodiversity and more access to larger variety of food resources (Heydari-Guran 2014; Stein *et al.* 2014).

Ecological niche models have been employed in several studies in identifying past climatic refugia of different taxonomic groups (Walker *et al.* 2009; Fuentes-Hurtado *et al.* 2016; Yousefi *et al.* 2020b; Barratt *et al.* 2021; Mulvaney *et al.* 2022). These studies highlighted usefulness of ecological niche models in reconstructing species palaeodistribution and climatic refugia (Walker *et al.* 2009; Fuentes-Hurtado *et al.* 2016; Yousefi *et al.* 2020; Barratt *et al.* 2021; Mulvaney *et al.* 2022). In this study, we showed that middle and northwestern parts of the Zagros Mountains have had high probability of being climate refugia for Epipaleolithic humans during the LGM. Zagros Mountains are known as important refugia for vertebrates of Iran like reptiles, mammals

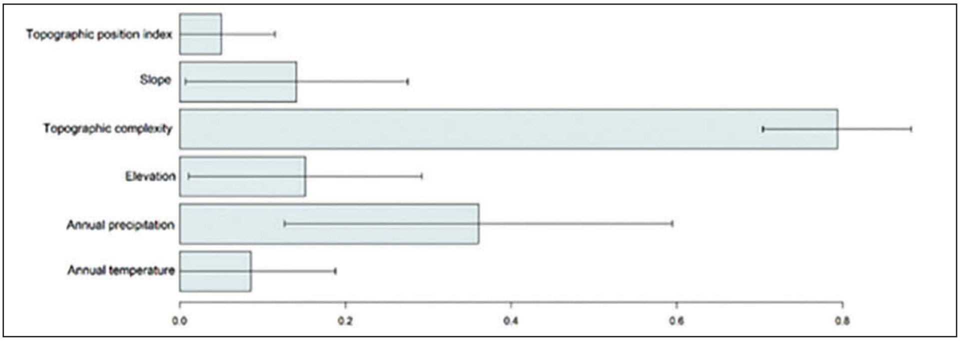


Fig. 3 – The relative importance of each variable in shaping Epipaleolithic settlement distribution.

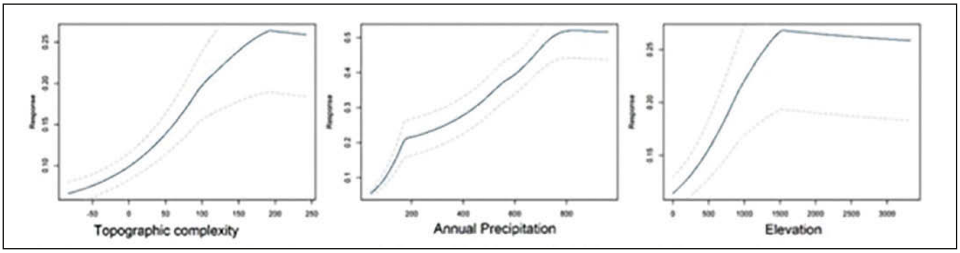


Fig. 4 – Response curve showing association of habitat suitability and the most important environmental variables.

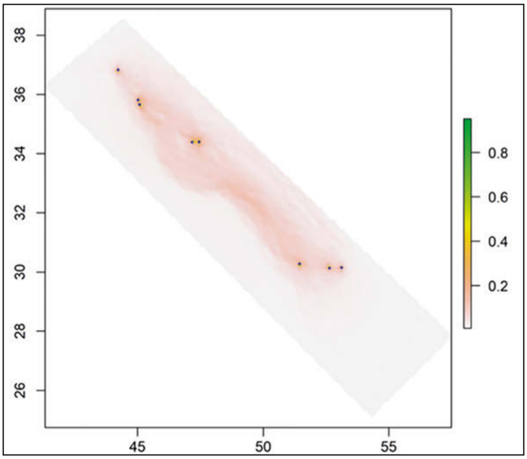


Fig. 5 – Movement corridors of the Epipaleolithic humans in Zagros Mountains.

and birds (reviewed in Yousefi *et al*. 2023). These mountains played equally an important role in survival, not only of human societies, but also of other species that have been hunted and exploited by ancient humans.

The corridors reconstructed based on the habitat suitability model shows areas that may have been used as dispersal corridors by the Epipaleolithic societies during the LGM. We recommend these areas as important target areas for archaeological field observation to further assess validity of these results and identification of Epipaleolithic occupations. Through this study we identified Epipaleolithic climatic refugia during the LGM, thus, the most promising areas have high priority for future field excavations.

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ABSTRACT

The Iranian Plateau is an important geographical unit located in a key potential region for the Pleistocene population dispersals across Eurasia. Despite its important location and a long history of archaeological investigations, the Epipaleolithic sites distribution pattern and connectivity remained less explored compared to the Middle and Upper Paleolithic periods. In this study we used ecological niche modelling (Generalized Linear Models, Generalized Additive Models, Generalized Boosting Models, Maximum Entropy Modelling and Random Forest), together with corridor mapping methods, to reconstruct the Epipaleolithic settlements and their connectivity in the Zagros Mountains. We showed that the central parts and the western slopes of the Zagros Mountains were the most suitable areas for Epipaleolithic settlement during the Last Glacial Maximum (LGM). Topographic complexity was the most important variable in shaping Epipaleolithic settlement distribution with a positive association. The niche model and corridors maps developed for the Epipaleolithic humans show areas potentially suitable for the presence of Epipaleolithic settlements but no site has been discovered in this area so far. Thus, these areas are having high priority for future field excavations.

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# BALANCING BETWEEN BIASES AND INTERPRETATION. A PREDICTIVE MODEL OF PREHISTORIC SCANIA, SWEDEN

## 1. Introduction

This contribution focuses on the distribution pattern of prehistoric sites in the county of Scania (*Skåne län*), Sweden (Fig. 1). The high number of archaeological investigations carried out in the past few years makes the area particularly suitable for predictive modelling. However, a closer look at the current situation shows that our knowledge is not uniform. In fact, some areas attracted more attention due to commercial archaeology or research interest. This is the case of the Malmö area, the West coast, the North-East and, in part, the Ystad area (Larsson *et al.* 1992; Artursson 2005, 2007; Sjögren 2006; Hadevik, Steineke 2009). The difference in research intensity introduces a set of possible biases in our knowledge, on top of the less controllable (but more predictable) recovery biases or information loss. Undoubtedly, our knowledge is heavily affected by post-depositional factors and modern activities such as agricultural activity or presence of infrastructures (Bevan 2012). The goal of this paper is to quantify and disentangle these different factors, as a first step before setting up interpretative models.

The dataset used for this paper is a subset of the Swedish National Heritage database (Riksantikvarieämbetet, RAA, https://pub.raa.se/). In particular, the study deals with Stone Age settlements and different types of prehistoric monuments dating between the Early-Middle Neolithic (EN-MN) and the Bronze Age (BA). These monuments should be analysed separately due to their nature but also because of the different histories of research underlying them. This is because some monuments (mounds, megaliths and cairns) are highly visible in the landscape and therefore known since a very long time even without thorough archaeological investigations (survey and excavations). Conversely, most of the prehistoric settlements were only known after the application of systematic surveys and modern excavations. Thus, they are the product of different processes and they are affected by different biases or to a different extent from each other. Considering them at once would increase the risk of interference or confounding.

The analyses presented in this paper are all carried within an R environment (v.4.2.1 R Core Team 2022), using a fully documented and reproducible approach. Unfortunately, despite soil and geological data could greatly contribute to this model, they were not included because they are not freely accessible. The paper is structured as follows: section 2 describes in detail the

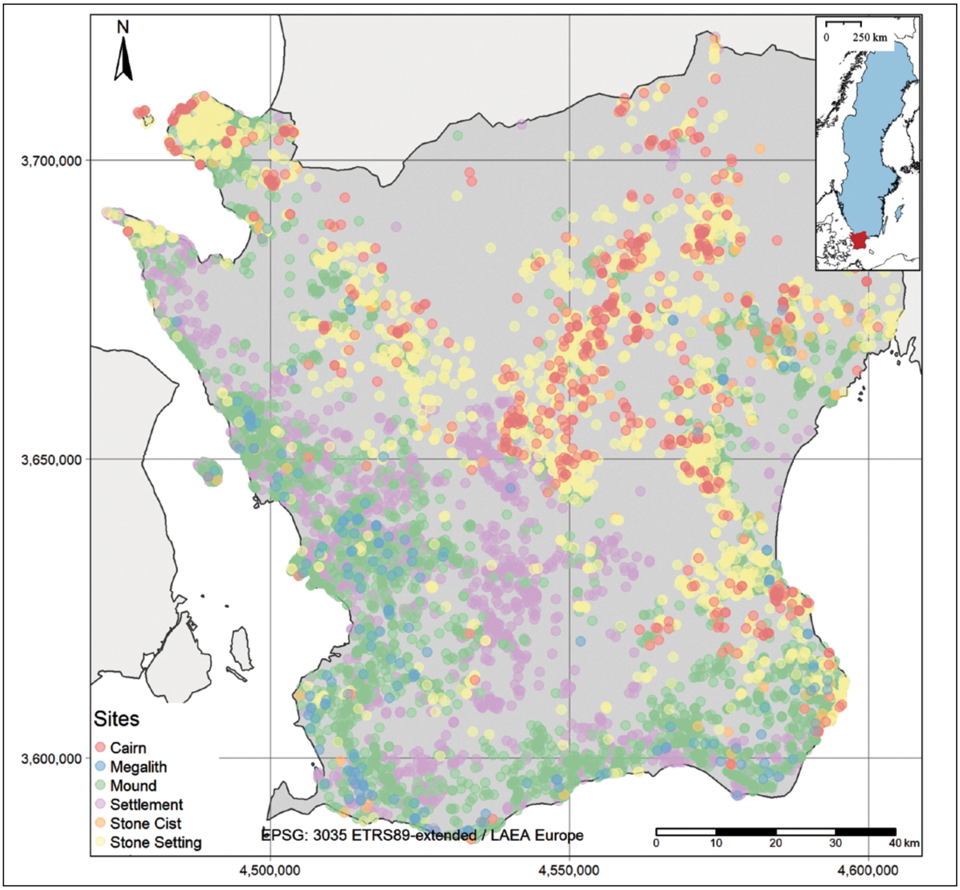


Fig. 1 – Sites and study area. On the top right corner the study area is shown on a map of Sweden.

starting data, the workflow followed and the analytical tools used; in section 3 the results are presented and section 4 discusses them with some additional remarks about future outcomes and caveats.

## 2. Data and methods

The data used for the analysis consist of sites and covariates. In order to be able to use them to feed the model they needed some filtering and editing. This section deals with the methodological and critical aspects of data and their handling.

## 2.1 *Data*

### 2.1.1 Archaeological data

The archaeological sites used in this study come from the Swedish Heritage database which can be freely accessed from Riksantikvarieämbetets öppna data server. In particular, data come from the *Fornlämningar och övriga kulturhistoriska lämningar* (Ancient monuments and other cultural-historical remains). As a whole, the dataset includes over sites from each (pre-)historical period. Here, only prehistoric sites belonging to the following typologies were considered: Stone Age settlements (*Stenåldersboplats*), megalithic tombs, burial mounds, cairns, stone settings. Stone Age settlements include all sites dating between the Mesolithic and the Neolithic. Unfortunately, most of them consist of stone scatters and cannot be precisely dated. These were found during field surveys and often contain mixed, un-datable or fragmented material. A refined chronology can be obtained only at the expenses of many sites. For this reason, it was decided to use them as they were, selecting the ones with a Stone Age dating. In total, 2162 sites belong to this category.

Megaliths are a special class of monuments that was built in some parts of Northern and Western Europe (Blank 2021, 20ss.). During the Funnel Beaker period (ca. 4000 BC-2800 BC in the area) two main types of megaliths were built in the study area: Dolmens and Passage graves. However, the period of megalithic construction can be restricted to the EN II-MN A II (3500-3000 BC), during the so called Klimax period (Persson, Sjögren 1995; Sjögren 2003, chap. 1). In the following degenerative period and up until the Late Neolithic (after 2300 BC) monuments were still in use but not built (other types are used, e.g. individual flat graves or gallery graves (Sjögren 2003; Blank 2021, chap. 7). In the study area 193 monuments are recorded.

Mounds, cairns and stone settings represent three different types of monuments, all interpreted as memorials and/or landmarks. Stone settings are the less impressive of the three types, but they are assumed to serve a similar function, especially when forming clusters or associated with nearby mounds (Nord 2009). What is relevant here is the difference in their construction and how this affects their preservation. Stone settings and cairns are both mainly made in stone, the former flat (or slightly domed) and the latter distinctly domed (Nord 2009,106). Mounds are earth made and have a grassy cover, although they often conceal a stone structure[1]. Most of the sites were built between periods I and IV of the Bronze Age (ca. 1700-900 BC), with

[1] It has been noted that the distinction is sometimes fuzzy (Nord 2009, 106), but this can only have an impact on single sites or a very local scale, which is not the focus here.

a peak in periods III and IV (1300-900 BC). In the Late Bronze Age fewer mounds were built and of a smaller size, whilst some older ones were used for secondary burials (Nord 2009, 103-104). From a simple distribution map we can already see some differences in the pattern, with mounds fairly widespread, with a predominance in the S and W of Scania, whereas cairns and stone settings are dominant in central and northeastern Scania (Fig. 1).

#### 2.1.2 Biases and landscape variables

Sample bias is one of the main problems when it comes to large datasets. Another significant problem relies in research biases, with some areas being in the centre of more intense activities than others. The final picture risks to be incomplete and a simple distribution map largely meaningless. Nevertheless, if properly accounted, there is still a large potential to obtain good results when analysing them (as shown in Bevan 2012).

In this study, distribution of infrastructures (urban agglomerations, roads and railways) and farmland were used as bias variables (Fig. 2). The variables can be downloaded from Open Street Map Geofabrik landuse server, either manually or using a dedicated function from the *rbias* package (Günther *et al.* 2022). For the landscape-based modelling the following variables were considered:

– elevation, with a 30 m resolution from the EU-DEM v1.1;
– slope and the SAGA Wetness Index, calculated from the elevation using SAGA GIS (Conrad *et al.* 2015) through R, using the package Rsagacmd (Pawley 2022);
– distance from the coastline and from rivers. River data derive from Open Street Map and are also freely accessible. The resolution of the rasters was set to 30 m.

### 2.2 *Methods*

This study investigates the differences in presence/absence of different classes of sites tested against modern land-use (infrastructures and agricultural) and then against geomorphological variables (elevation, distance from resources, soil, etc.). The workflow is very simple and mostly based on the functions available in the *rbias* package (Günther *et al.* 2022):

– select the desired land-use data (they can be downloaded using the download_geofabrik_data function) and stack them into a single vector using the dissolve_osmdata function;
– create a distance raster using the bias_surface function. This step was also used to compute distance from the coastline and rivers;
– use the function bias_influence to create a fuzzy raster (based on Knitter, Hamer 2022) with values scaled between 0 to 1 (low to high bias). In short,

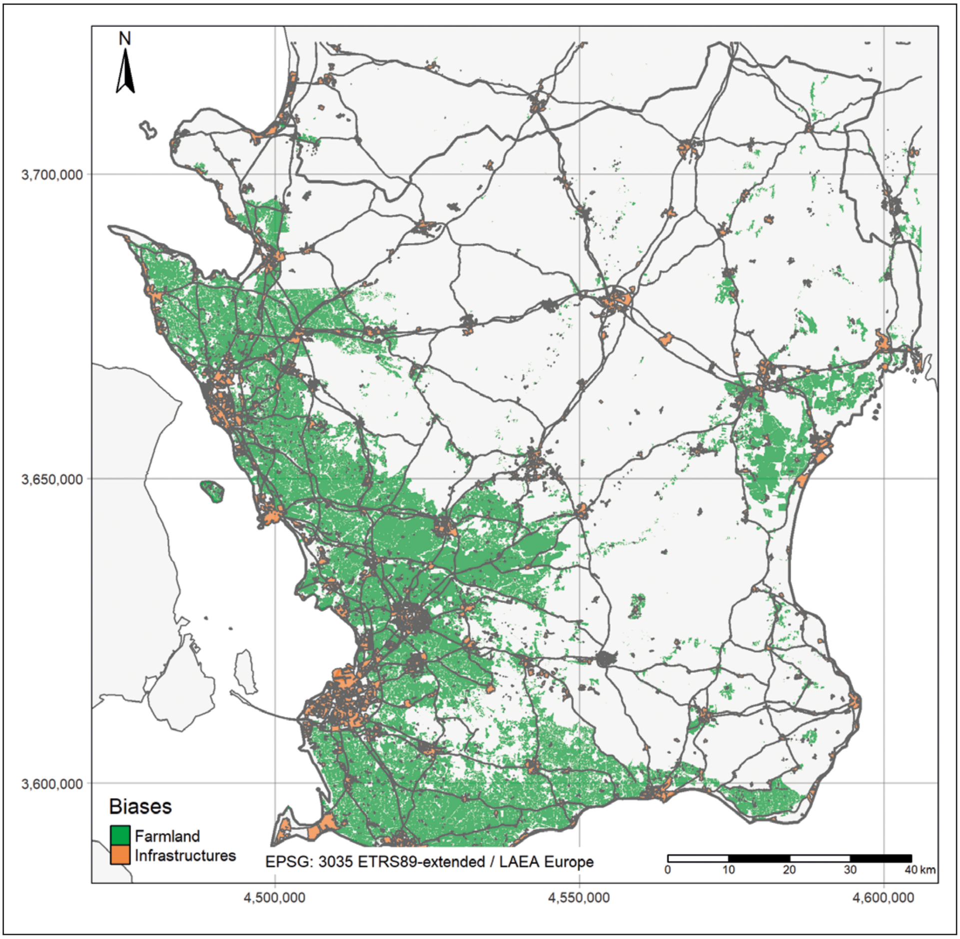


Fig. 2 – Maps of the biases used in this study (data/Maps copyright 2018 Geofabrik GmbH and OpenStreetMap Contributors).

it uses a decay function to attribute a value to every raster cell. Here, a triangular transformation with a decreasing bias from 0 m (inside the area) to 250 m was used. Of course, these values could be easily modified in order to fit different requirements. Distance from rivers and coastline were used as they were, without fuzzification;

– test the density of observations against the background using the function sites_vs_background. The function creates a frequency plot for each covariate at sampling locations, simulating the background as random sampling process with a 95% confidence interval (based on Bocinsky 2017);

– when a bias is identified, a new subset of the area is cropped according to the bias surface and only the spatial patterns of the archaeological sites within this smaller study area are tested against the landscape variables. The main idea is to obtain a region where the bias is assumed to be uniform.

## 3. Results

Settlements and megaliths are analysed separately while the other monuments are analysed together because of their similar chronology and function. The first part is dedicated to the identification of possible biases, followed by an analysis of covariate influence based on the results of the first step as described in Section 2.2.

### 3.1 *Stone Age settlements*

Settlements are highly correlated with the presence of farmland (Fig. 3a). The most likely explanation is that most of the recorded settlements were found during surveys, more likely to be carried on accessible land and more successful on ploughed soils. The other parameters also show some correlation, but this is generally close to the confidence interval. The lower impact of cities at very short distance (approaching 1, i.e. inside the city) could indicate that settlements are under-represented there, possibly due to their destruction during urban expansion in times when archaeological investigations were not routine. It is possible that if we remove larger cities from the analysis the result will be similar to Bevan (2012).

In order to have a more homogeneous study area for the subsequent analysis, only the settlements found on farmland were considered, assuming a uniform bias. The results are instructive, showing that the background influence is very strong. Nevertheless, we can observe that settlements occur more frequently than expected at elevation between 30 and 60 m (Fig. 3c). This is a good result if we compare the same analysis carried on the entire study area. In terms of distance from the sea or rivers, the behaviour shows slight preference for proximity to water sources (Fig. 3d-e).

### 3.2 *Funnel Beaker megaliths*

As for the settlements, farmland seems to have a strong impact in the distribution of these monuments, with higher than expected numbers in it or its proximity and less at increasing distances. A very similar pattern can be observed also for cities and infrastructures[2] (Fig. 4a-b). In general,

[2] Inside urban areas (values tending to 1) they are not found more frequently than expected by chance alone.

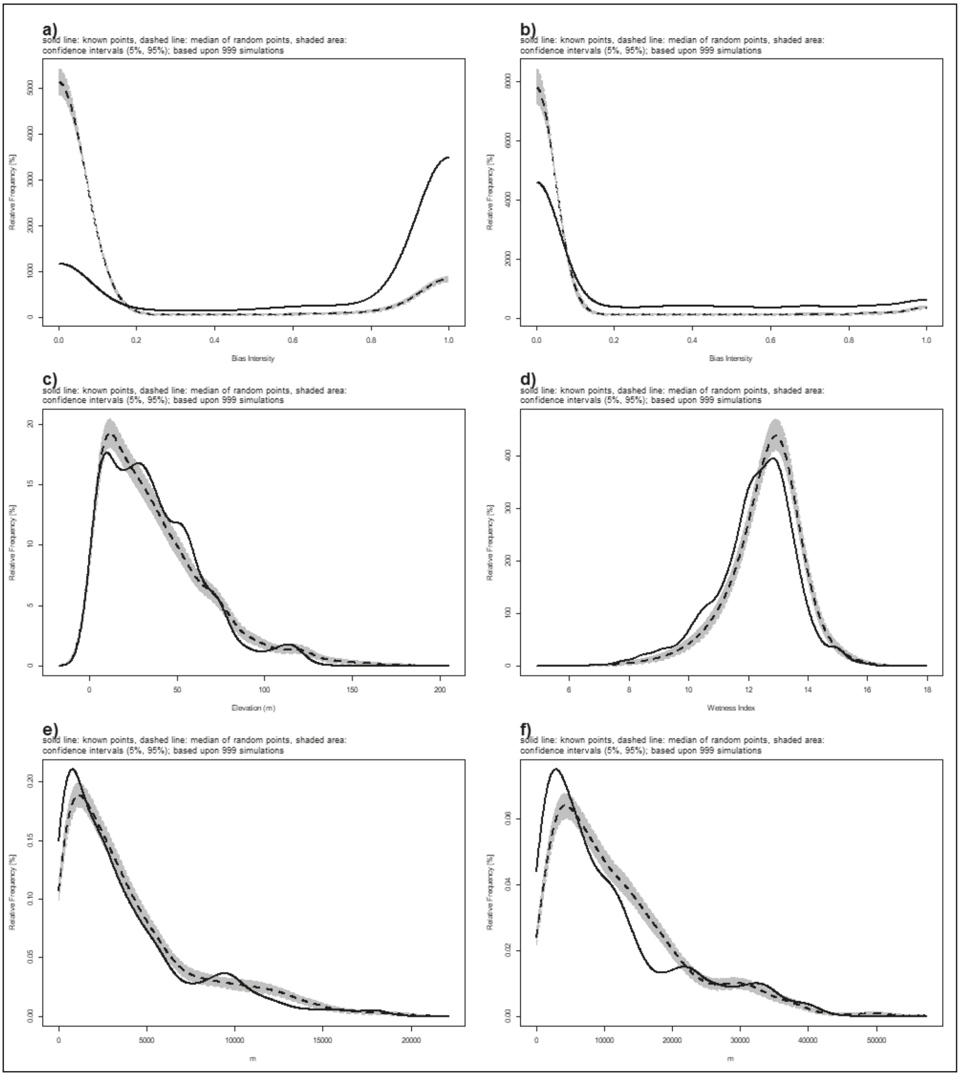


Fig. 3 – Settlement frequency plots: a) farmland as covariate; b) infrastructures as covariates; c) elevation; d) SAGA Wetness Index; e) distance from rivers and from the sea as covariates using the reduced study area as background.

their pattern does not differ greatly from what we observed for settlements. However, if we reduce the study area to the farmland we observe that proximity to the coast becomes a very good predictor, with a peak of site frequency at around 5 km and a higher presence of monuments compared

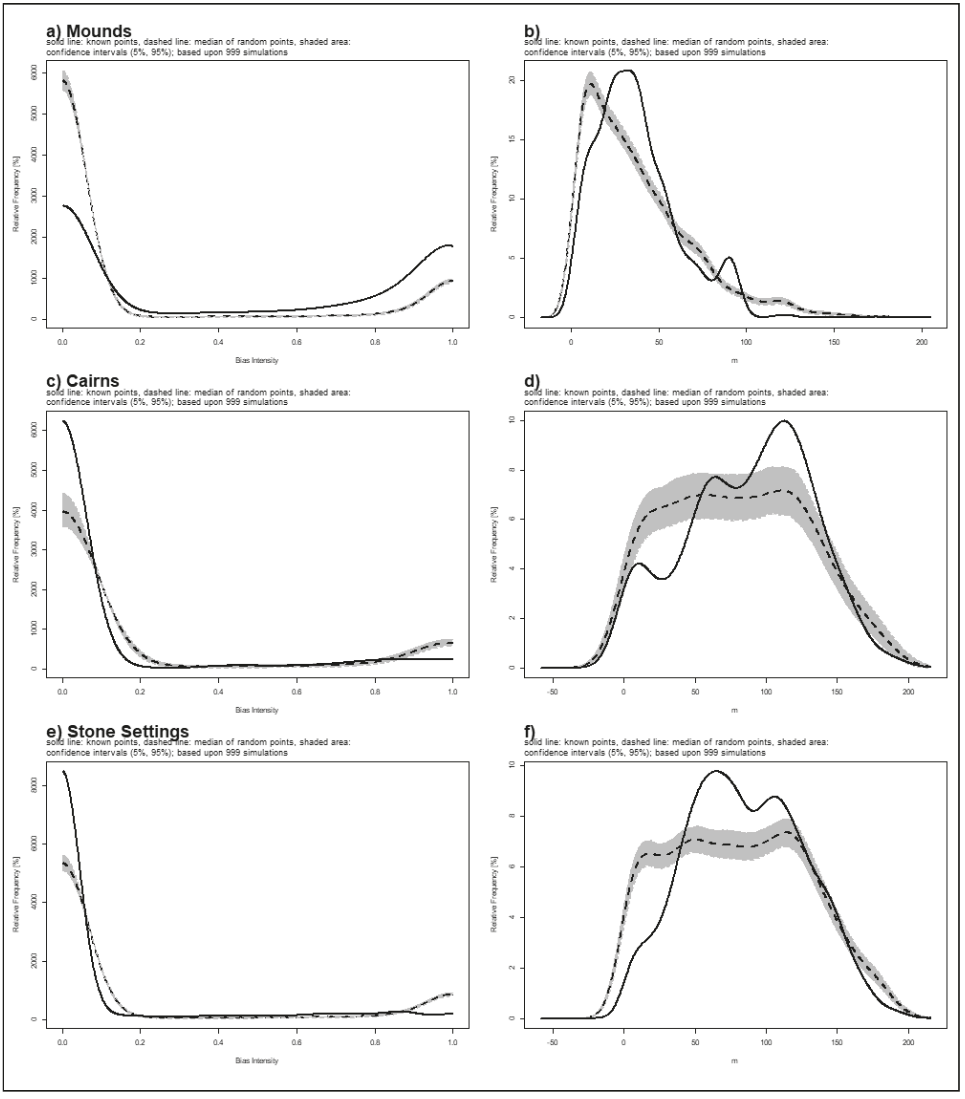


Fig. 4 – Megalith frequency plots: a) farmland and b) infrastructures as covariates; c) elevation and d) distance from the sea as covariates using the reduced study area as background.

to a completely random distribution (Fig. 4d). Elevation, which was a good predictor also before sub-setting the area, does not change, with more sites than expected by chance alone below 40 m asl ca. and fewer above 50 m asl (Fig. 4c).

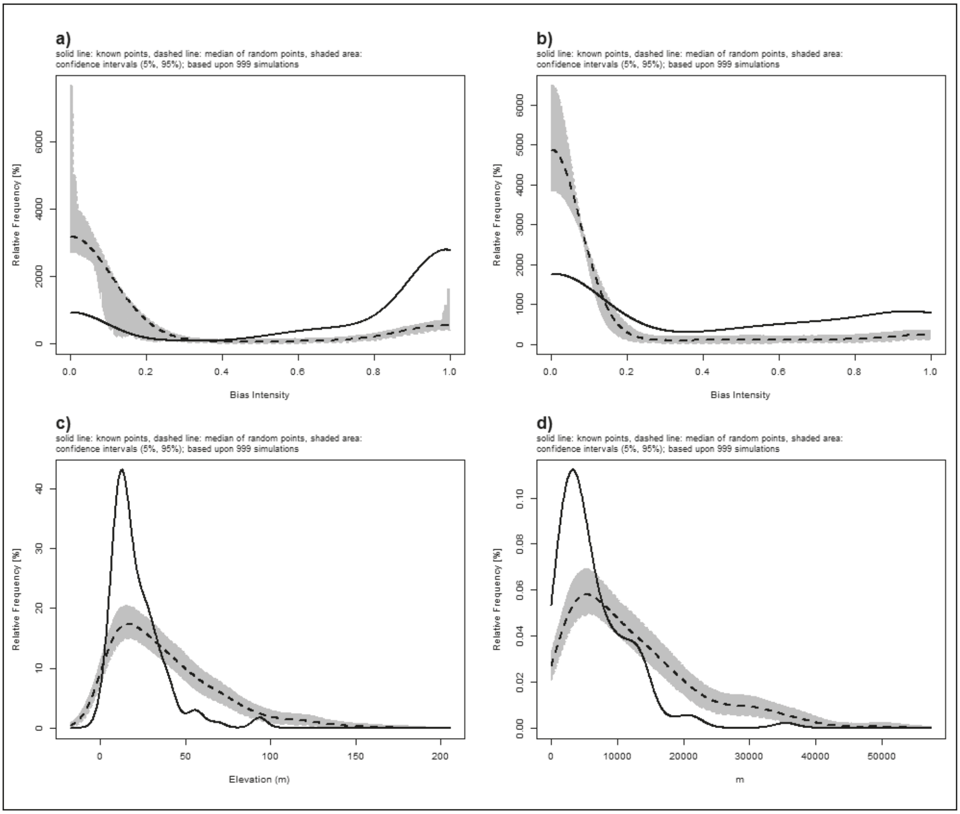


Fig. 5 – BA monuments frequency plots. Mounds: a) farmland as covariate; b) elevation (restricted area); cairns: c) farmland as covariate; d) elevation (restricted area). Stone settings: e) farmland as covariate; f) elevation (restricted area).

## 3.3 *Mounds, cairns and stone settings*

Mounds have a strong bias due to modern farmland but they also show a strong positive correlation with elevation. In fact, burial mounds tend to occur at low-intermediate elevation, with a peak around 40-50 m asl ca., while the farmland peaks at elevations closer to the sea level (Fig. 5a-b). In addition, mounds tend to occur more likely near the sea (peak below 5 km, and mostly below 10 km) and less than expected by chance alone at higher distances.

Cairns and stone settings tend to appear outside farmland, which is therefore excluded from the subsequent analysis. Again, elevation seems to be a very good predictor, with more stone settings than expected by chance alone between 50-100 m and cairns at 100-150 m and fewer than expected monuments below 50 m asl (Fig. 5c-f). In addition, cairns seem to occur with more frequency at higher distances from the coastline (> 35 km) and on drier soils (their Wetness Index, WI, is substantially lower than the surroundings). Stone settings have a similar behaviour in terms of WI, while they have a more composite behaviour in terms of distance from the sea, with two distinct peaks, one below 10 km and the other at 30-50 km. It is not possible to exclude that agricultural field clearances destroyed many of these monuments at different locations, but their distribution pattern seems to be complementary to the one of mounds, reinforcing an archaeological interpretation of the observed pattern. In addition, their behaviour does not substantially change when we use the entire study area or a subset.

This is an important result because it diverges from Neolithic monuments and settlements, giving us insights in different population patterns between the EN-MN and the Bronze Age.

## 4. Conclusions

Although a strong bias seems evident for many classes of sites, their impact is variable. When it is very strong, as for settlements, it is more challenging to suggest a reliable model but some hypothesis are nonetheless possible, given the fact that the distribution of megalithic burials partially reflects settlement pattern. However, only a more sophisticated model (on which I am currently working) could shed more light over population patterns during the Stone Age. This is not the case for the Bronze Age. In this case, the different classes of monuments have a complementary behaviour, strengthening our confidence in the model and reducing uncertainty already at this stage. Certainly, this paper only represents the first step for a more thorough analysis of prehistoric population patterns, which requires the inclusion of more variables and an organic combination into a more sophisticated environmental and social model.

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## ABSTRACT

Southern Sweden, and especially the area around Malmo in southwestern Scania, is perhaps one of the most archaeologically investigated areas in the world. Our knowledge of the local Prehistory has greatly increased in the past decades although it is also the product of centuries of agricultural practices, urban expansion and a relatively early (18$^{th}$-19$^{th}$ c.) interest for prehistoric monuments (e.g. burial mounds and megaliths). However, despite the deluging amount of available information (over 50,000 ancient sites recorded in Scania), their distribution is not homogeneous and archaeologists are restlessly trying to explain this pattern and its underlying causes. In addition, post-depositional factors

(infrastructure works, agricultural practices, etc.) heavily affect site distribution and preservation, blurring the global interpretation. The aim of this paper is to reduce the impact of post-depositional factors on our interpretations on site distribution. In addition, the results can be used as a starting point for further and more elaborate analyses (spatial statistics and simulations). All the models presented here were computed in a reproducible way, relying on FOSS and open data only, in order to allow anyone interested to replicate the model and adapt it to their own purposes and study regions.

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# FROM LEGACY DATA TO SURVEY PLANNING? THE RELATIONSHIP BETWEEN LANDSCAPE AND WATERSCAPE IN SOUTHERN TUSCANY DURING THE UPPER PALAEOLITHIC: TOWARDS A PREDICITIVE-POSTDICTIVE APPROACH

## 1. Introduction

The present work focuses on the relationship between the prehistoric landscape and waterscape of Southern Tuscany (central Italy) during the Upper Palaeolithic – between 38.000-12.000 years BP – with the aim of analysing the peopling processes linked to the significant changes taking place in its coastal district. In order to address the biases implicit in this research objective, a postdictive approach was used with the goal of establishing a framework on which to develop future research. The irregularly progressive decrease in global temperatures, culminating with the Last Glacial Maximum (LGM) between 30.000 and 16.000 BP, produced the maximum global ice volume and lowest sea level, making way to vast new surfaces and land masses that emerged as sea levels dropped. The dramatic effects of these changes influenced the displacement of human populations and the establishment of various subsistence or settlement strategies. Today, much of this landmass has once again been submerged, a series of geomorphological transformations, which have also occurred inland, affecting the visibility and conservation of prehistoric traces in the archaeological record.

This paper presents the first stages of this predictive-postdictive analytical process (Arnoldus-Huyzendveld *et al.* 2016), with particular focus on data input build-up: namely the geomorphologic settings useful for understanding the main effects of landscape-waterscape changes, as well as the acquisition of legacy data, which in this case study constitute a key archaeological source.

## 2. Methodological approach

This currently ongoing research is centred on Southern Tuscany and the islands of the Tuscan Archipelago which provide a unique context for assessing changes in the local waterscape and how this affected the peopling processes during prehistory. Heterogeneous evidence attests to the presence of Upper Palaeolithic human communities in today's coastal areas, revealing the attractiveness of these contexts. Moreover, archaeological evidence recorded at the inland cave site of Grotta del Sambuco (Massa Marittima, Grosseto) suggest that during the Upper Palaeolithic, human groups living in the hinterland were willing to travel long distances in order to benefit from the marine resources available in the coastal area (Pizziolo 2020, with references). While difficult to envisage daily treks, it is nevertheless possible to hypothesize that a "trip-to-the-seashore" may have been part of that form of subsistence mobility associated with inland communities.

How can we explore this landscape-waterscape relationship that influenced the lives of Palaeolithic groups? In order to increase our understanding of settlement dynamics and to address the relevant biases associated with these issues, a postdictive approach has been proposed with the aim of establishing a framework on which to develop future avenues of research. With these considerations in mind, it is worth setting up a GIS system to obtain landscape-waterscape surfaces related to LGM changes while integrating various archaeological proxy data so as to analyse, from a predictive-postdictive (Arnoldus -Huyzendveld *et al.* 2016) perspective, the prehistoric landscape. The final goal of the project will be to answer a series of questions posed by the postdictive approach, although in the current stage of the research it is first necessary to establish the prehistoric setting and reflect on the various biases associated with it.

## 3. The study area: a transect to test procedures

The research is centred on the Grosseto district, specifically on a geographical transect defined according to watercourses. The study area includes different land units, morphologies and waterscapes, providing a heterogeneous landscape useful for testing the aforementioned methodological approach and analytical procedures. Starting from the NW, the transect (Fig. 1) is bounded by the Cecina river, encompassing the southern portion of the district of the Colline Metallifere; towards the NE it reaches the junction between the Merse and Ombrone rivers, including to the S the territory as far as the Albegna river. The present-day landscape is generally hilly, with the exception of the northern sector where the mountainous reliefs form an important watershed between different catchment areas. In the southern part of the Grosseto district, during the Etruscan and Roman period, the Bruna and Ombrone rivers formed a wide alluvial plain occupied by the Prile lake. This water basin gradually developed into a swamp, until land reclamation activities, carried out until the 20$^{th}$ century, drained most of the wetlands. It should be noted that these recent activities deeply affected the possibility of reconstructing prehistoric contexts dating back to the Upper Palaeolithic, as they were covered by reclamation deposits.

Conversely, in the southern coastal area, the Monti dell'Uccellina and the promontory of the Argentario constitute two intact calcareous reliefs, morphological landmarks offering natural resources and cave shelters to prehistoric peoples. Moreover, as already mentioned, the coastal area was markedly different from how it appears today. We must remember that during the LGM (Lambeck *et al.* 2014), when the sea reached approximately -120 m below the

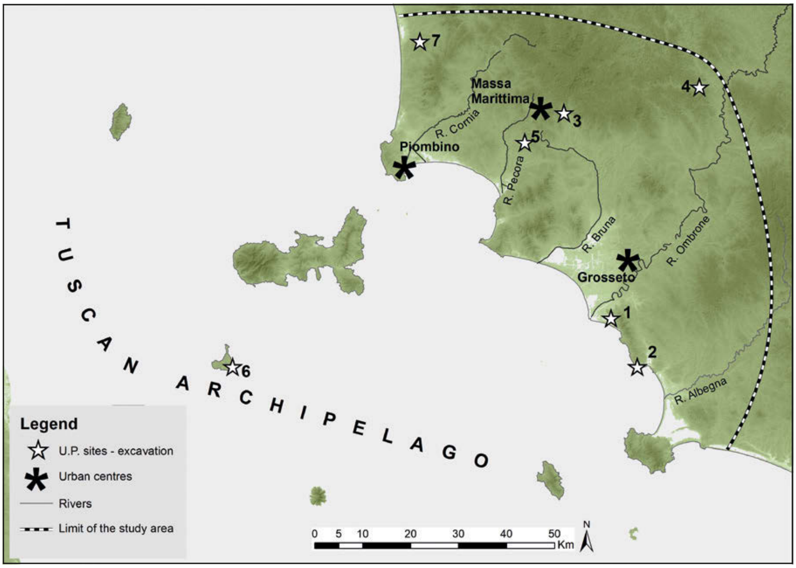


Fig. 1 – The study area. Upper Palaeolithic cave and open-air sites (stratigraphic evidence): 1) Grotta La Fabbrica; 2) Grotta Golino; 3) Grotta del Sambuco; 4) Petriolo; 5) Vado all'Arancio; 6) Grotta di Cala Giovanna; 7) Greppi Cupi (I and II).

current level, nearly all the islands of the Tuscan Archipelago formed a single land mass with the mainland. According to global reconstructions of sea-level changes (see as a general reference Benjamin *et al.* 2017), the waterscape-landscape relationship from 38.000 to 12.000 years BP was quite dynamic, entirely different from Holocene settings, and difficult to define at a local scale.

## 4. Upper Palaeolithic contexts: first level of data input

The stratigraphic evidence from the Upper Palaeolithic period documented in the study area is mainly related to cave sites excavated in recent decades. One of the most significant in the coastal area is Grotta La Fabbrica, located on the western slopes of the Monti dell'Uccellina and which has preserved an important prehistoric sequence attesting to the intensive use of the cavity (Dini, Tozzi 2012) during the Middle and Upper Palaeolithic (Mousterian, Uluzzian, Aurignacian, Gravettian - Epigravettian). In addition to this cave, other surface evidence related to Uluzzian and Aurignacian phases has been recorded in coastal (Monte Argentario, Freguglia 2008) and inland areas (Massa Marittima and Petriolo), also near jasper outcrops used as raw material (Galiberti 1970). On the southern side of the Monti dell'Uccellina, the site of Grotta di Golino shows the presence of a partially excavated and now lost

Gravettian layer, as work was carried out between the 19th and 20th century. On the contrary, the ongoing excavation at Grotta del Sambuco (Massa Marittima) reveals a stratigraphic sequence that attests to the long use of the karstic cavity: Gravettian (SU 6 – 23.632±150 BP), Epigravettian (SU 4 13.615±75 BP) and Holocene evidence (Neolithic and historical phases) (Calattini *et al.* 2015-17).

An increase in the number of archaeological sites is documented in the district of Grosseto during the Epigravettian, a trend in line with the rest of the peninsula, with caves, shelters and open-air contexts linked to dwellings or funerary activities. The Epigravettian evidence analysed throughout the stratigraphic sequence refers to the final Epigravettian, recorded at Grotta del Sambuco (SU 4) and at the shelter of Vado all'Arancio (Massa Marittima, 11.600±130 BP, Minellono 1980), the latter also revealing the presence of numerous engraved bone artefacts as well as two burials.

As for the landscape/waterscape relationship, the role of the Ombrone river must also be considered. Gravettian and Epigravettian evidence, in fact, is also attested at the site of Petriolo (Donahue, Chartkoff 1983), located at the confluence of the Farma and Ombrone rivers, an area rich in thermal springs. The analysis of lithic artefacts from the cave site of Grotta di Cala Giovanna (Grifoni Cremonesi 1971), located on the shoreline of the Island of Pianosa and excavated in the 19th century, suggests that the cave was inhabited during the initial phases of the Final Epigravettian. Along the coast, in the area of Donoratico, stratigraphic investigations in the Pleistocene sands documented two small temporary structures at Greppi Cupi I and II (Tozzi, Dini 2007), dating to the last phases of the Final Epigravettian. Greppi Cupi II, a sunken hut dwelling with artefact scatters, revealed the use of local raw materials collected from nearby riverbeds, whilst the faunal remains are referable to a woodland environment; the shelter feature at Greppi Cupi I, on the other hand, attests to the continuity of use of this site even in the transition phase to the Mesolithic.

## 5. The reconstruction of landscape changes: a first step

At this stage of the project it is necessary to set up a palaeogeographical framework in which to insert archaeological data pertaining to that period of dynamic landscape changes that occurred before and after LGM, in the interval 35-12 ka BP. In this regard, it is crucial to know when and how the coastal changes occurred, as well as in what form the Tuscan Archipelago was actually part of the peninsula. To indicate the general trend, we refer to Global Mean Sea Level curves (Lambeck *et al.* 2014; Benjamin *et al.* 2017) even though we are aware that values may differ at a regional or local scale of analysis. The current focus is on the general reconstruction of different scenarios, without taking into account local factors due to isostatic and tectonic activities (Vacchi *et al.* 2016), alongside erosion and deposition factors related to geomorphological

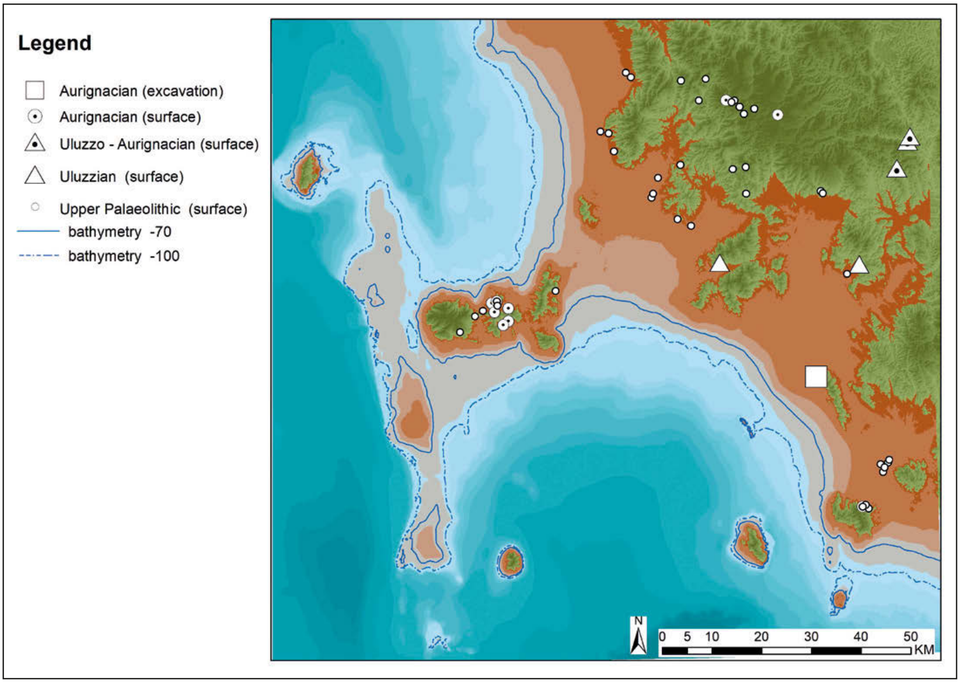


Fig. 2 – Landscape reconstruction of the case study transect during the Aurignacian. Marked in the legend are excavated sites and archaeological surface evidence.

changes. When the sea levels dropped, new land masses emerged and a new uninterrupted landscape was made available to human groups. Presently, our main goal is to obtain a general overall shape of that setting, calculated from the seabed surface of today. Available bathymetric data from EMODnet Digital Bathymetry (DTM 2020 - EMODnet Bathymetry Consortium - 2020), which offers a harmonised model generated from selected bathymetric survey datasets and Satellite Derive Bathymetry (SDB), were used to reconstruct this scenario.

The EMODnet DTM was logged into the GIS and combined with the detailed land DTM available from the Tuscan regional authority. The combination of these DTMs was used to establish different scenarios related to the main phases of the Upper Palaeolithic. Based on the sea level curves (Benjamin *et al.* 2017, fig. 4), the various palaeo-shorelines that characterised the landscape/waterscape dynamics in the past were plotted. Observing the different simulations, it is possible to note that during the Aurignacian (-70/-100 m below the present sea level), the islands of the Archipelago formed the promontories of a new gulf (Fig. 2); during the Gravettian (-100/-120 m) they became the headlands of a much narrower gulf (Fig. 3); whereas

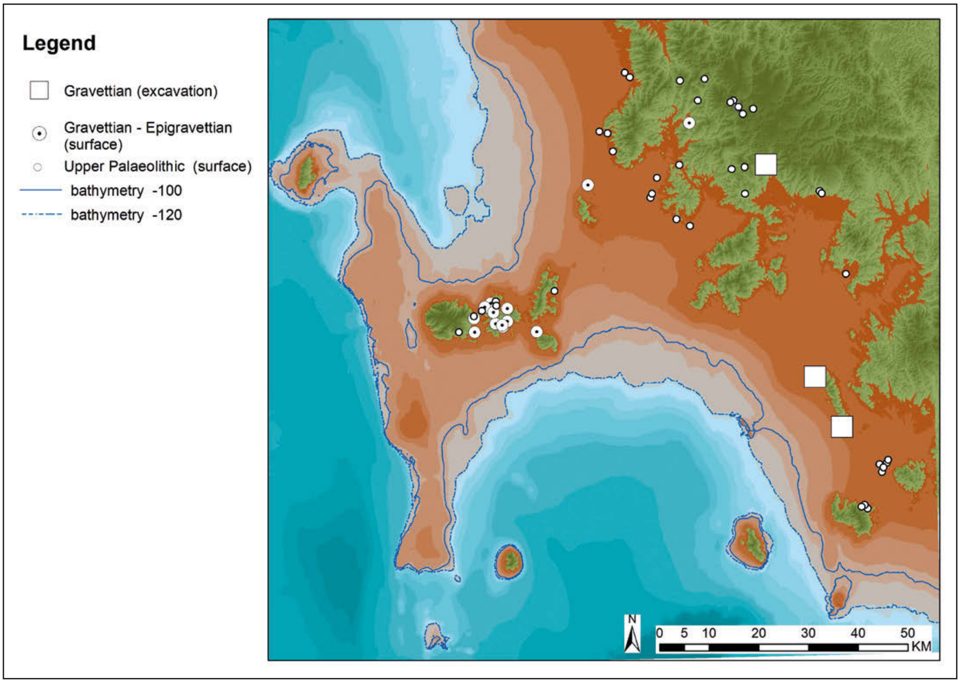


Fig. 3 – Landscape reconstruction of the case study transect during the Gravettian. Marked in the legend are excavated sites and archaeological surface evidence.

during the Epigravettian the sea level rose again (-85/-50 m), but the islands of Pianosa and Elba continued to remain connected to the mainland, respectively until the early and final phases of the period (Fig. 4). Furthermore, the use of EMODnet DTM enables to draw sections and profiles of the seabed's morphology, allowing to examine in detail the possible palaeo-connections between the present-day mainland and the nearby islands.

## 6. Legacy data and virtuous processes

In these new scenarios, the distribution of Upper Palaeolithic evidence (Fig. 1) appears as an uneven record of the peopling process and not so significant in the landscape/waterscape perspective. To improve the dataset, evidence from previous surface records was included, even at the risk of introducing generic information into the system. Since the 1960s, several non-systematic surveys have been carried out in the study area; sporadic finds were also recorded. Reports of these activities were published in an assortment of journals, bulletins and catalogues (as a reference: Pizziolo 2020 with references).

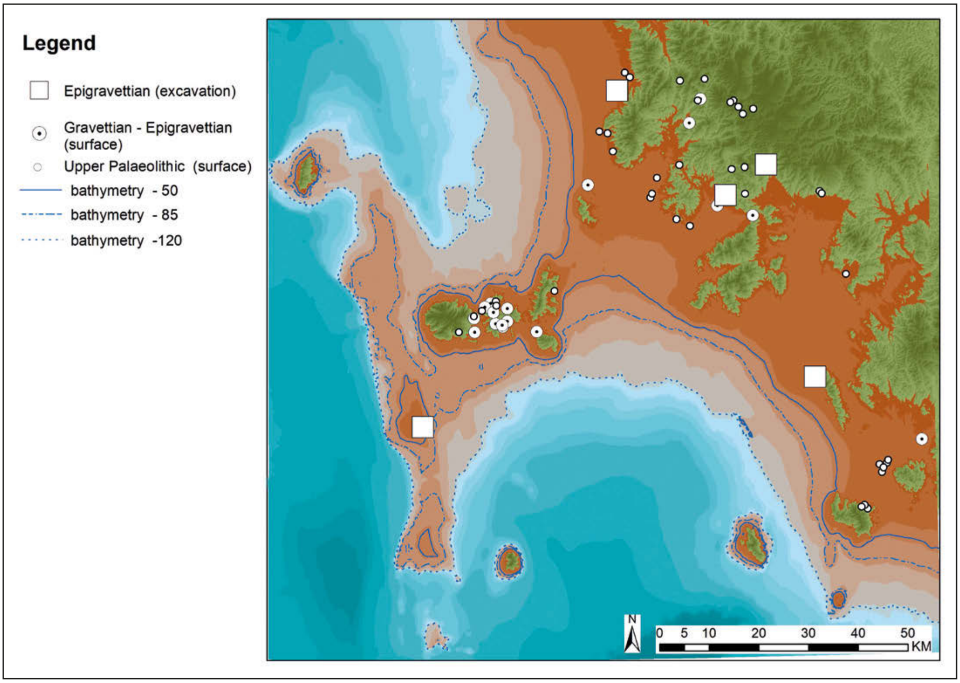


Fig. 4 – Landscape reconstruction of the case study transect during the Epigravettian. Marked in the legend are excavated sites and archaeological surface evidence.

In order to reduce bias, these legacy data were analysed and sorted in a DB according to the following criteria: depositional characteristics; quantity and quality of the finds; chronology; extent and accuracy of the location. Some surface records documented significant assemblages referable to single or double phases. Others are only generically attributable to the Palaeolithic. By managing this information through GIS it was possible to obtain a general assessment of its reliability and relevance.

Thus, legacy data, although less accurate, can be used as proxy data attesting to the spread of human groups across the territory (Figs. 2, 3, 4). The analysis of the geomorphological context of some stratigraphic evidence can provide new insights for the identification of topographical features and geological formations with archaeological potential (Pizziolo, Volante 2015 for similar analysis criteria). To implement this approach, geological maps at different scales were added into the system. The most effective elaborations were obtained by adopting the maps which provide details on coastal formations and a selection of Pleistocene deposits of the Tuscan regional authority at a scale of 1:10.000. In this case, the archaeological information

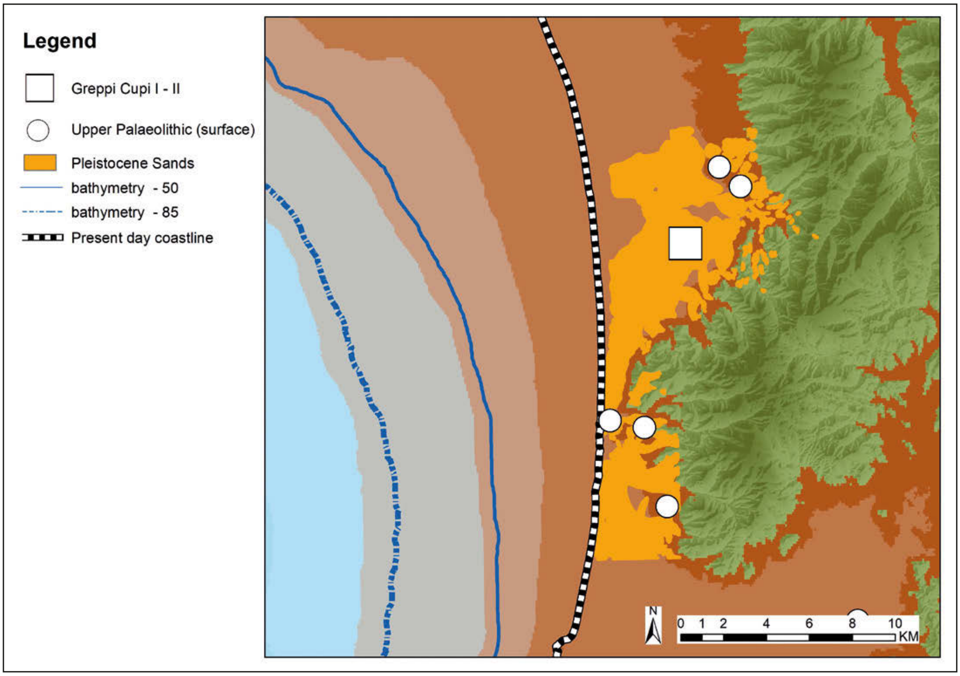


Fig. 5 – Greppi Cupi (Epigravettian): the relationship with the Pleistocene sands and other Palaeolithic evidence (from the Tuscan regional geological map 1:10.000).

of the Greppi Cupi sunken features, excavated in Pleistocene sands (*supra*), was included, defining the extent of these sandy deposits in the area (Fig. 5). This approach contributes towards a better understanding of settlement strategies, investigating why certain choices were made in relation to the general layout of the (present-day) coastal board, while simplifying the identification of relict features related to the prehistoric landscape.

In short, a sort of virtuous and circular process has been constructed: a) the distribution of sites or off-sites on the surface helps identify relict features of the prehistoric landscape and b) select morphological and sediment criteria to recognize them; then c) assess and predict potential areas for new investigations. It is interesting to note, from a predictive-postdictive perspective, that the Pleistocene sands around Greppi Cupi during the Epigravettian were not shoreline features but originally part of the upper coastal belt, possibly surrounded or in the vicinity of woodland, as testified by the faunal remains recorded from the site (*supra*). The distribution of Palaeolithic surface evidence on the Pleistocene sands of Donoratico offers new hints in planning further investigations in that area.

## 7. Conclusive remarks

The critical acquisition of archaeological legacy data has provided an important support to our predictive-postdictive approach. Once evidence obtained from surface collections as well as bathymetric and geomorphological data were added into the GIS, it was possible to explore different prehistoric landscape scenarios. Moreover, it is possible to return to some of our initial questions, suggested by the analysis of Grotta del Sambuco, focusing on Upper Palaeolithic settlement strategies and their involvement in waterscape and marine resources. Observing the different Upper Palaeolithic reconstructions, one can note that a series of possible activities (dwellings, artefact production, hunting, raw material procurement) are spread in the form of sites or off-sites, providing newfound insights in the reading of hills, coastland and archipelago land units. The Island of Elba attracted Aurignacian groups, but in particular Gravettian-Epigravettian communities, consolidating our idea of attraction/interest in the paleo gulf as already witnessed by the cave of Cala Giovanna at Pianosa (*supra*).

The upper coastal belt and the inner valleys have revealed evidence as to the presence of circulating human groups, suggesting new hypothesis on possible "trip-to-the-seashore" behaviours and relative traces. Nevertheless, further analyses of geological maps along with the assessment of erosion/deposition factors, must be carried out before attempting a postdictive cost surface (Citter, Patacchini 2018) in order to build a postdictive least cost path. The study is still in progress.

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## ABSTRACT

During the Upper Palaeolithic, Southern Tuscany was strongly affected by geomorphological changes that significantly altered its coastal seaboard. In particular, during the Last Glacial Maximum, the sea reached a level below 100 meters. As a result of this, the prehistoric coastland included also the present Tuscan Archipelago, in particular the Islands of Elba and Pianosa, assuming a different layout during Marine Isotope Stage (MIS) 3 and 2. In this context, the process of prehistoric occupation took place, according to different needs and criteria. The present work explores the possibility of investigating the dynamic relationship between the prehistoric landscape and waterscape by a predictive-postdictive approach. Alongside the simulation of coastal changes, the study makes use of legacy data, taking into account those derived from artefact surface scatters collected over the past decades by various research groups. The latter provide further evidence of the prehistoric occupation process. In this scenario it is crucial to highlight areas that potentially still retain some relict features of the Palaeolithic landscape. These are examined in order to better understand settlement strategies taking place during the Upper Palaeolithic and, at the same time, to investigate the relationship between inland and coastal sites in a diachronic perspective. Although still ongoing, preliminary results provide new elements for the planning of future field surveys.

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# LO STUDIO DI SITI ARCHEOLOGICI DI ALTA QUOTA: METODOLOGIA E RISULTATI DEL MODELLO PREDITTIVO IN AMBIENTE GIS APPLICATO NELLE VALLI DI LANZO (PIEMONTE, ITALIA)

## 1. Introduzione

Il progetto Tracce Preistoriche in Ambiente Alpino (TPAA) nasce dalla collaborazione tra la Soprintendenza Archeologia Belle Arti e Paesaggio per la Città Metropolitana di Torino, il Dipartimento di Studi Umanistici dell'Università degli Studi di Ferrara e l'Associazione 3P (Progetto Preistoria Piemonte) per avviare progetti di ricerca scientifica, valorizzazione, supporto alla tutela e formazione del patrimonio archeologico pre-protostorico e paleontologico del territorio delle Valli di Lanzo, Orco e Soana, nelle Alpi Graie, a NO di Torino. Infatti, mentre i dati archeologici per la preistoria nelle Alpi orientali sono abbondanti e studiati (Kompatscher, Kompatscher 2007), nelle Alpi occidentali sono lacunosi e sporadici, se non per alcune puntuali ricerche. Indagini sul campo sono state effettuate nel territorio montano della Valsessera (Biella), individuando siti con fasi di frequentazione mesolitica, neolitica e di età romana (Berruti *et al.* 2016; Rubat Borel *et al.* 2016; Caracausi *et al.* 2018); dal 2018 sono state avviate ricerche anche nelle Valli di Lanzo (Rubat Borel *et al.* 2020), una revisione delle industrie litiche del Paleolitico medio sulle Vaude nel Canavese occidentale e del Paleolitico medio e del Mesolitico nella alta valle dell'Elvo nel Biellese (Berruti *et al.* 2021, Daffara *et al.* 2022).

In letteratura, le Valli di Lanzo sono note solo per contesti o reperti successivi al Neolitico medio derivati da ritrovamenti occasionali o, più raramente, rinvenuti durante l'attività di assistenza archeologica per cantieri (Rubat Borel *et al.* 2020). Con questo progetto viene applicato un approccio multidisciplinare (modello predittivo e analisi sul campo) per cercare contesti archeologici. Il modello predittivo è necessario per diverse ragioni: 1) l'ambiente alpino è accessibile solamente in estate e nel primo autunno; 2) è necessario un miglioramento del tempo utilizzato per la ricerca sul campo; 3) l'interpretazione dei risultati ottenuti richiede l'applicazione di diverse metodologie per la ricerca sul campo; 4) il contesto geografico delle Valli di Lanzo non permette una diffusa attività di ricerca durante l'intero anno.

Grazie all'applicazione di questo modello predittivo è stato possibile individuare Aree Potenziali Archeologiche che sono state sottoposte ad attività di ricerca negli anni 2019-2020.


Fig. 1 – Inquadramento geografico dell'area di studio, nel rettangolo l'area delle Valli di Lanzo.

## 2. L'area di studio

Le Valli di Lanzo con una superficie di 583 km$^2$ occupano il settore meridionale delle Alpi Graie e costituiscono il bacino idrografico del fiume Stura di Lanzo, affluente di sinistra del Po (Fig. 1). I corsi d'acqua principali sono Stura di Viù, Stura di Ala e Stura di Val Grande, con una orientazione WE. I principali rilievi sono, in ordine di altezza decrescente, l'Uja di Ciamarella (3676 m s.l.m.), la Bessanese (3604 m s.l.m.), il massiccio con le due cime vicine della Croce Rossa (3566 m s.l.m.) e della Punta d'Arnas (3560 m s.l.m), la Levanna Orientale (3555 m s.l.m.) ed il Rocciamelone (3538 m s.l.m.). Geologicamente le Valli di Lanzo si pongono al centro dei processi orogenetici nella formazione delle Alpi occidentali e si suddividono, da W ad E, in quattro domini: Unità superiori del Sistema Pennidico, Zona Piemontese, Sistema Austroalpino Sesia-Lanzo e Massiccio di Lanzo.

La Val Grande, la più settentrionale, si sviluppa principalmente all'interno del Sistema Pennidico, con litologie formate da rocce metamorfiche derivanti da graniti tardo-paleozoici e, con minore estensione, con litologie della Zona Piemontese e della Zona Sesia-Lanzo. Le litologie della Zona Piemontese, che affiorano nelle Valli d'Ala e di Viù, sono costituite da ofioliti, calcescisti metamorfici. Mentre nella Valle di Viù è presente, oltre alle precedenti litologie della Unità Zona Piemontese, una sottile fascia di rocce appartenenti alla Zona Sesia-Lanzo, costituita da gneiss ricchi in albite, raggruppati nel complesso degli "gneiss minuti".

Il modellamento dei versanti e dell'attuale paesaggio è legato alle dinamiche glaciali-interglaciali del Pleistocene inferiore, quando i grandi ghiacciai hanno allargato, approfondito e riprofilato le Valli di Lanzo (Piana *et al.* 2017).

Nell'area sono riconoscibili tre grandi collettori dei ghiacciai, che corrispondono alle testate iniziali delle tre valli al confine con la Francia. Il successivo modellamento, al ritiro dei ghiacciai, si manifesta con processi di erosione fluviale e processi deposizionali, con la formazione di conoidi allo sbocco dei torrenti tributari nelle valli principali con limitati depositi alluvionali di fondovalle. Il risultato dei diversi cicli erosivo-deposizionali è visibile, ad esempio, nella Valle di Viù, su entrambi i versanti vallivi dove si riscontrano rotture di pendenza e di superfici terrazzate. Le incisioni da corsi d'acqua hanno andamento prevalentemente rettilineo, con elevate pendenze che favoriscono un'intensa azione di erosione a carico dei depositi quaternari, rappresentati da falde detritiche e antichi depositi glaciali; mentre, a quote più basse, sono presenti accumuli gravitativi in parte quiescenti con profonde incisioni e massi erratici.

## 3. Metodologia del modello predittivo

Il modello effettua una interpolazione tra diversi dati e si adegua al contesto ambientale del territorio; parte dalla metodologia utilizzata in alta Val Sessera (Berruti *et al.* 2016; Rubat Borel *et al.* 2016; Caracausi *et al.* 2018) introducendo dei parametri di filtraggio. La costruzione del modello si è articolata in quattro fasi:

1) Definizione di potenziale archeologico. Il potenziale archeologico è la probabilità che si sia conservata una traccia archeologica e nel modello indica le possibili aree da sottoporre a ricerca. Questa fase è correlata alla ricerca bibliografica e archivistica di rinvenimenti archeologici o di fasi di frequentazione storica.

2) Individuazione dei parametri utili alla realizzazione del modello predittivo. Il modello predittivo valuta i dati ambientali e il contesto archeologico del territorio. In questo lavoro è stato preso in considerazione il modello

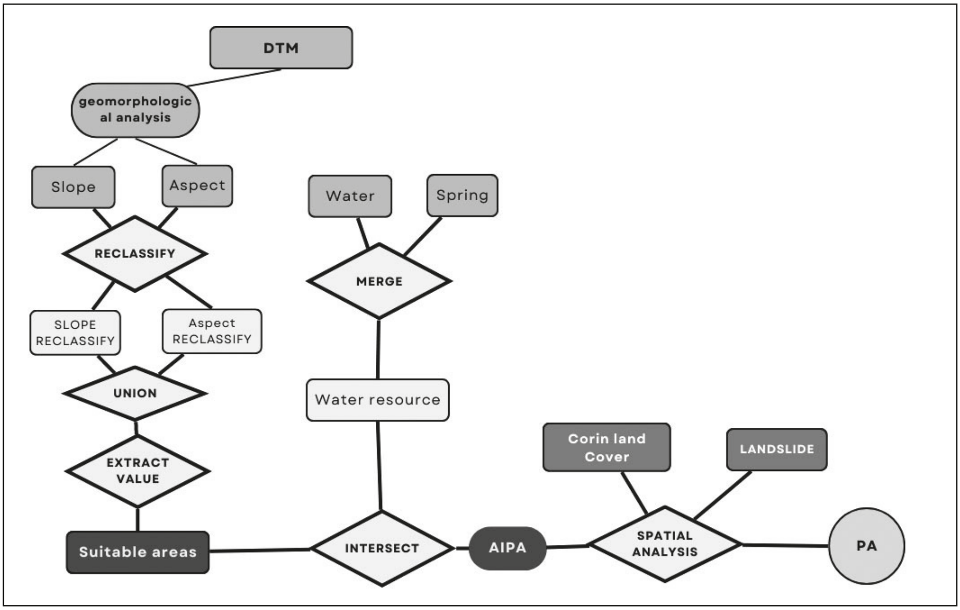


Fig. 2 – Modello logico della costruzione del modello predittivo. I rettangoli sono i dati utilizzati e i prodotti, mentre con i rombi si intende l'applicazione dei geoprocessing tools di QGIS; nel cerchio, il prodotto finale: la mappa del Potenziale Archeologico.

di insediamento e di mobilità in ambiente alpino utilizzato nelle ricerche in Valle Sessera, che ha permesso di individuare siti di interesse archeologico. Dal confronto tra l'alta Valsessera e le Valli di Lanzo, il territorio risulta simile, con presenza di corsi d'acqua perenni alimentati da deflusso superficiale. I parametri utilizzati per discriminare il territorio sono: distanza dalla risorsa acqua; visuale sul territorio circostante; esposizione dei versanti rispetto all'irraggiamento solare; uso del suolo; movimenti franosi e pendenza dei versanti.

3) Creazione del dato e filtraggio. L'approccio alla costruzione del modello con logica booleana (Stančič, Kvamme 1999) in cui una variabile può assumere solo due valori, "1" (SI) o "0" (NO), permette una semplificazione dei parametri diretti e indiretti e delle relazioni tra ambiente e uomo. Il prodotto finale è l'individuazione di aree con parametri uguali a 1 rispetto alla possibile presenza di siti archeologici (Fig. 2). I dati sono forniti dal Geoportale della regione Piemonte, attraverso la banca dati BDTRE (Base Dati Territoriale di Riferimento degli Enti) per modellazione digitale del terreno (DTM) e per fonti idriche. Il sistema di riferimento è in UTM con datum WGS 1984 e zona 32N mentre il DTM ha una risoluzione 10 m (https://www.geoportale.piemonte.it/

geonetwork). Tutti i dati sono processati con QGIS 3.6 Noosa (Quantum GIS Development Team 2018) e suddivisi in diversi gruppi di layer informativi dove sono contenuti gli shapefile dei dati archeologici e ambientali. Per l'analisi morfometrica del territorio sono utilizzati i parametri dell'esposizione dei versanti, della pendenza e dello studio delle fonti idriche. Tutti i comandi sono presenti nel menu "strumenti di geoprocessing" in QGIS. Il programma calcola l'esposizione dei versanti, suddividendo il range di valori continui in 360°, ponendo il N=0 e ruotando in senso orario.

L'applicazione della metodologia booleana necessita di dati discriminati; quindi, è stata effettuata una riclassificazione, con il raggruppamento dei singoli valori in range, tramite l'apposito tool (riclassifica raster) e suddividendo l'esposizione dei versanti in 4 settori: N (315°-45°); E (45°-135°); S (135°-225°); W (225°-315°) con l'attribuzione del valore 1 alle aree con esposizione a S (135°-225°). Sono scelti i versanti esposti a S, poiché quelli esposti a N hanno un microclima più rigido a causa del regime dei venti. La pendenza, ricavata dal DTM, ha un valore continuo da 0 a 90°. In maniera analoga al parametro esposizione, il parametro pendenza è riclassificato in 4 classi di valori espressi in percentuale: 1 (0-11); 2 (10-16); 3 (16-20); 4 (20-25); 5 (>25); utilizzando il comando unione "merge" tra la pendenza e l'esposizione, esportiamo le aree con valore 1 rinominate "Suitable Areas". La risorsa acqua "Water Resource", intesa come sorgenti o laghetti, è una unione dei dati idrici presenti nel BDTRE attraverso un "merge" e con un buffer di 80 m (Strumenti di Geoprocessing\Buffer). Applicando un overlay spaziale con il comando "intersezione" tra il layer "Suitable Areas" e il layer "Water Resource" ricaviamo un layer di output con zone che presentano le condizioni del modello teorico: aree sub pianeggianti, esposte a S e in vicinanza della risorsa idrica. Questo nuovo dato prende il nome di "archeological potential suitable areas" o Aree Idonee per il Potenziale Archeologico (AIPA).

L'ultima fase è la pulitura/filtraggio; i filtri applicati sono l'utilizzo del suolo e la presenza di movimenti franosi. Il filtraggio del parametro "uso del suolo" è stato condotto attraverso la sovrapposizione tra le AIPA e l'utilizzo del suolo ricavato dal progetto Corine Land Cover (2018). La mappa del Corine Land Cover permette di escludere le superfici artificiali, le zone agricole, le zone con colture permanenti, le aree a boschi a latifoglie e le aree conifere e/o miste e zone antropizzate. Le aree franose delle Valli di Lanzo sono state ricavate dal catalogo del Sistema Informativo frane in Piemonte (SIFRaP 2009). L'operazione di filtraggio è effettuata sempre con un overlay spaziale utilizzando il comando di "differenza" dove il layer di output contiene tutte le aree del layer di input che non si sovrappongono (intersecano) con il secondo layer di input. Il risultato finale è l'individuazione di aree idonee per la ricerca sul campo.

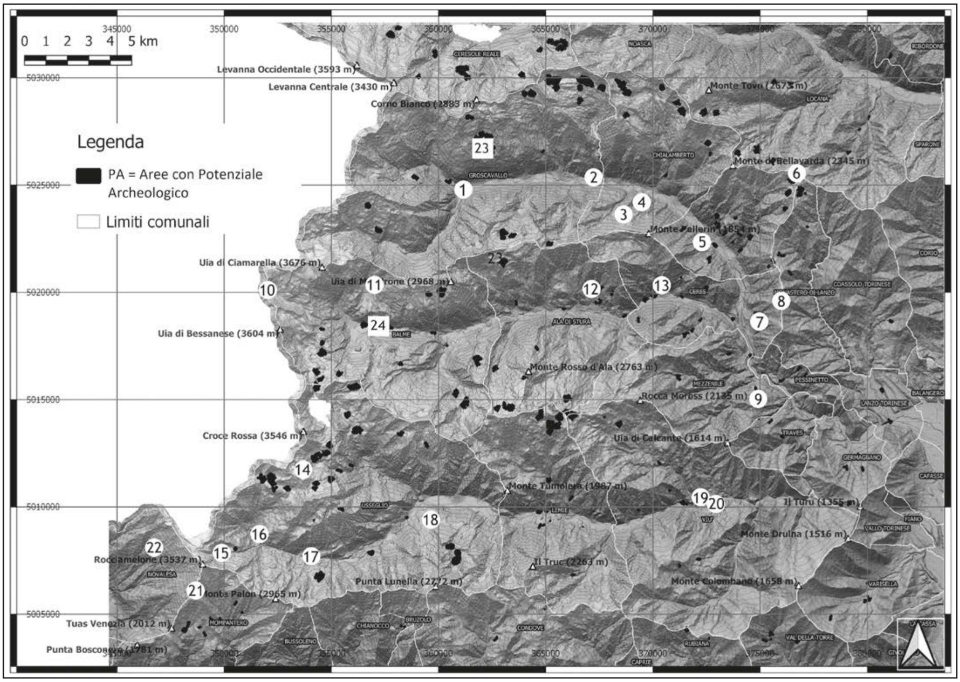


Fig. 3 – Mappa del Potenziale Archeologico: nei cerchi i siti e/o reperti preprotostorici conosciuti in bibliografia, mentre nei quadrati (n. 23 e 24), i siti individuati dopo le campagne di ricerca 2019-2020 in aree indicate dal modello predittivo (immagine modificata da Rubat Borel *et al.* 2020).

4) Avvio della ricerca sul campo. Dalla mappa del Potenziale Archeologico sono state scelte le aree da indagare nelle campagne di ricerca 2019-2020 nel comune di Groscavallo (Val Grande). La metodologia di indagine adottata segue le indicazioni dell'archeologia del paesaggio e consiste nella registrazione e documentazione di qualsiasi intervento umano sul paesaggio naturale.

## 4. Risultati

La mappa Potenziale Archeologico (PA) mostra le aree con una maggiore probabilità di individuare un contesto archeologico e di poter svolgere attività di ricerca (Fig. 3). Ciò ha ridotto l'estensione delle aree nelle Valli di Lanzo da quasi 600 km$^2$ a 3,2 km$^2$. La maggior parte dei ritrovamenti archeologici pre-protostorici noti ricade in queste aree o in prossimità (Rubat Borel *et al.* 2020, fig. 23). Sulla mappa sono state individuate due zone sottoposte a una campagna di ricerca nel 2019-2020. Queste campagne rientrano nell'ambito

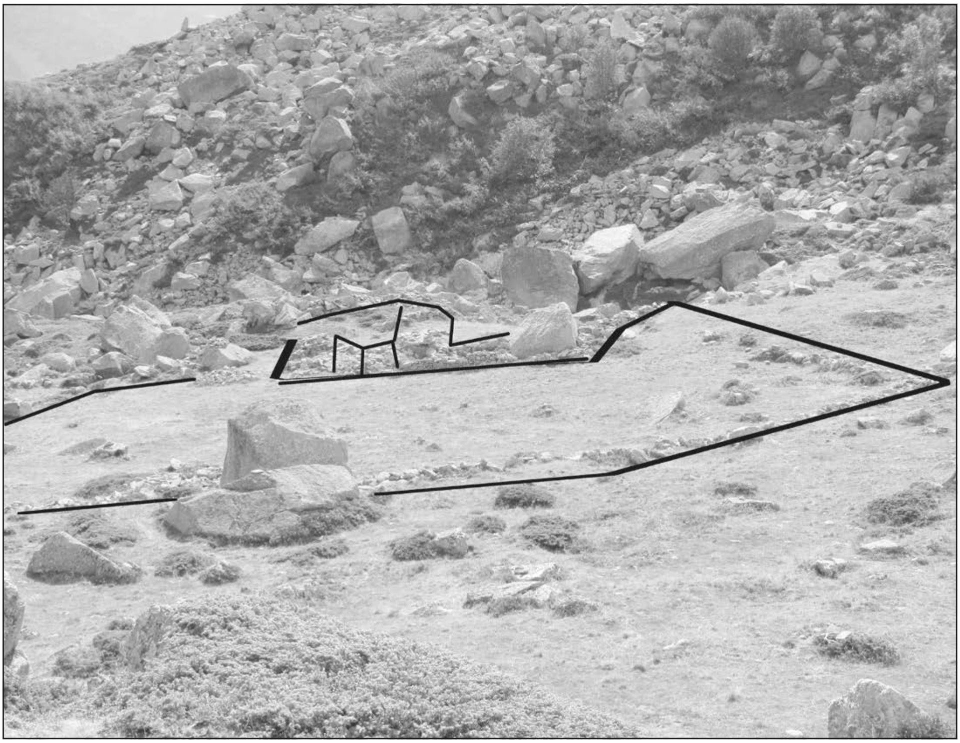

Fig. 4 – Sito n. 23. Insediamento con tracce di strutture abitative non presenti nella cartografia storica, dove sono stati rinvenuti strumenti antecedenti al XVII secolo.

del bando Club Alpino Italiano CAI - Terre Alte 2020, sono state realizzate in collaborazione con l'Associazione 3P - Progetto Preistoria Piemonte e CAI Lanzo e hanno permesso di individuare diversi ripari sottoroccia naturali o parzialmente utilizzati (localmente chiamati *balme*) che saranno, in futuro, sottoposti a ulteriori studi.

L'area oggetto di prospezioni corrisponde al percorso che va dalla strada consortile per Gias Nuovo Fontane ai laghi di Sagnasse. L'area, rivolta a S, è al di sopra dell'attuale linea del bosco, a circa 1750 m s.l.m. Lungo il percorso sono state individuate forme geomorfologiche legate all'azione di antichi ghiacciai quali: laghetti intorbati, massi erratici e piccoli pianori, sottoposti a documentazione fotografica, per prossime ricognizioni e campionature. L'area pianeggiante limitrofa al lago superiore mostra resti di strutture e piccoli ripari ricavati con muri a secco presso massi erratici, che suggeriscono frequentazioni di età storica la cui effettiva cronologia e consistenza dovrà essere determinata con ulteriori indagini.

A quota 2090 m s.l.m. è ubicato un ampio riparo sotto roccia con strutture costituite da allineamenti di cumuli di pietre, perpendicolari alle curve di livello, inizialmente interpretati come risultato di attività di spietramento finalizzate all'ampliamento delle aree a pascolo. Presso il riparo è stata realizzata una campionatura ragionata dove sono stati rinvenuti un bossolo datato al 1891 e una roncola, di una tipologia diffusa intorno al XVIII secolo. L'area con maggiori potenzialità è localizzata lungo la strada consortile sopra menzionata. Si tratta di una conca pianeggiante tra 1900 e 1920 m s.l.m., ampia tra i 100 e i 120 m, al centro della quale sono ben visibili i resti di strutture in pietra interpretabili come i resti di due grandi recinti e di alcune strutture abitative e/o funzionali all'attività pastorale (Fig. 4). Le caratteristiche degli oggetti rinvenuti sono databili tra XVIII e XIX secolo; tuttavia, il sito risulta assente da tutta la cartografia storica consultabile e dalla documentazione archivistica e sembra essere antecedente al XVII secolo: i confronti con simili strutture nelle Alpi occidentali fanno propendere per una datazione bassomedievale o precedente (Rubat Borel *et al.* 2021). I primi risultati di queste campagne, a cavallo con la pandemia Covid-19, hanno fornito una risposta positiva al modello predittivo aiutando a comprendere le modalità del popolamento delle Valli di Lanzo, dall'antichità all'età moderna.

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## ABSTRACT

The aims of TPAA Project (Traces Prehistoric in the Alpine Environment) are the research, promotion and protection of the archaeological heritage in the Lanzo Valleys in Graian Alps, Western Alps (Turin, Piedmont, Northwest Italy). This paper illustrates the GIS predictive model results for the identification of archaeological sites in Lanzo Valleys and the 2019-2020 field survey. The archaeological data stem from occasional findings or traces of rock art. The aim of the GIS predictive model is to identify Potential Archaeological areas for the presence of archaeological sites and to hypothesize any reconstruction of human frequentation dynamics in Western Alps. Predictive GIS model has been elaborated through the interpolation and interpretation of the different environmental and archaeological data available. In the GIS predictive model, criteria such as the geomorphology, distance to water resources, aspect, slope and the use of land were considered. Also, the methodology is an evolution of the one that has already been successfully employed in the Sessera Valley. The results of the GIS model are compared with archaeological data collected during field surveys in the Potential Archaeological areas.

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# FOOD, DISTANCE AND POWER. MODELING A MULTI-FACTOR PROTO-HISTORIC LANDSCAPE IN THE PO PLAIN

## 1. Introduction

AMPBV simulator is a Spatial Agent Based Model (SABM) developed in Netlogo software and programming language (Wilensky, Rand 2015) to analyze, through a simulative approach, the case study of the Northern Terramare polity in the Valli Grandi Veronesi (Fig. 1). The model is the latest research tool developed as part of the AMPBV (Alto Medio Polesine – Bassa Veronese) project, active since 1982 under the direction of Prof. Armando De Guio and mainly focused on archaeological investigation through non-impact (or minimal impact) techniques (De Guio *et al.* 2015). The model purpose is to take advantage of ABM bottom-up logic to better understand the processess and the main factors that may have led the protohistoric communities of the North-Eastern Po plain, from their peak to an almost sudden collapse. The goal, in particular, is to assess the impact of climate changes on the settlements survival.

## 2. From the Terramare landscape to a digital environment

The rise of the Terramare culture was one of the most significant and impacting phenomena in Northern Italian Protohistory. The Terramare society acquired in short time the typical traits of a polity, with «a level of complexity comparable to a simple chiefdom» (De Guio 1997, 155). A rapid demographic increase had also led to a major territorial reconfiguration: the new settlement system was hierarchically hinged on a few larger villages ("first rank settlements") such as Castello del Tartaro, Fabbrica dei Soci or Fondo Paviani sites. The repercussions on the landscape were considerable, mainly due to intensive land exploitation for structure building and agriculture, to meet the growing necessity of food production. Traces of Terramare occupation are still detectable from both field surveys and remote sensing (Buriganа, Magnini 2017); the abundant evidence collected so far in the area, as well as experimental data, served as a fundamental source of information to set some key-aspects of this complex anthropogenic system and to choose how to represent them in our model.

As in any ABM, AMPBV simulator includes, in addition to multiple agents, an environment and a set of rules defining the simulation processes (Epstein, Axtell 1996). Being a SABM, it relies on physical space as an explicit component (Manson *et al.* 2020). The main class of agents represented

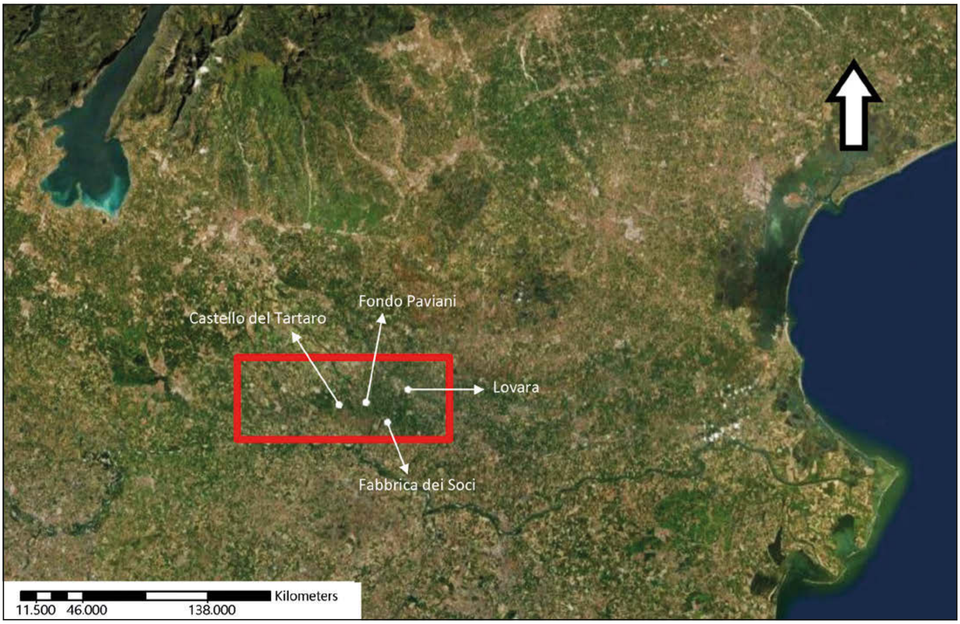


Fig. 1 – Framing and localization of the investigated area.

(*sites*) are the sites local communities, which have as their primary goal their own survival. Despite being stationary, sites behave like alive entities, they communicate and relate to each other, they produce, grow, suffer, and can eventually die. According to the implemented ruleset (Fig. 2), in order to survive sites need to provide enough food to their population, by producing it or by purchasing it through exchange. As the reference food resource we considered cereals (taking into account five different crop species), as they were likely to be the main component (approximately the 70%) of nutritional intake (Cattani *et al.* 2021).

In this context, spatial distance and resources of the physical landscape, but also the exchange network play a crucial role in the balance of the system. Therefore, the environment in AMPBV simulator has been reproduced in multiple forms, taking advantage of different representation entities in Netlogo:

– A "relational landscape" of inter-sites economic power in which inter-site relations are visualized as "relational links".
– A mobility environment as a regular network of "connective links", with values based on travel cost.
– A landscape of "patches", representing the territory physical features and related to movement and resource management. Both links and patches are

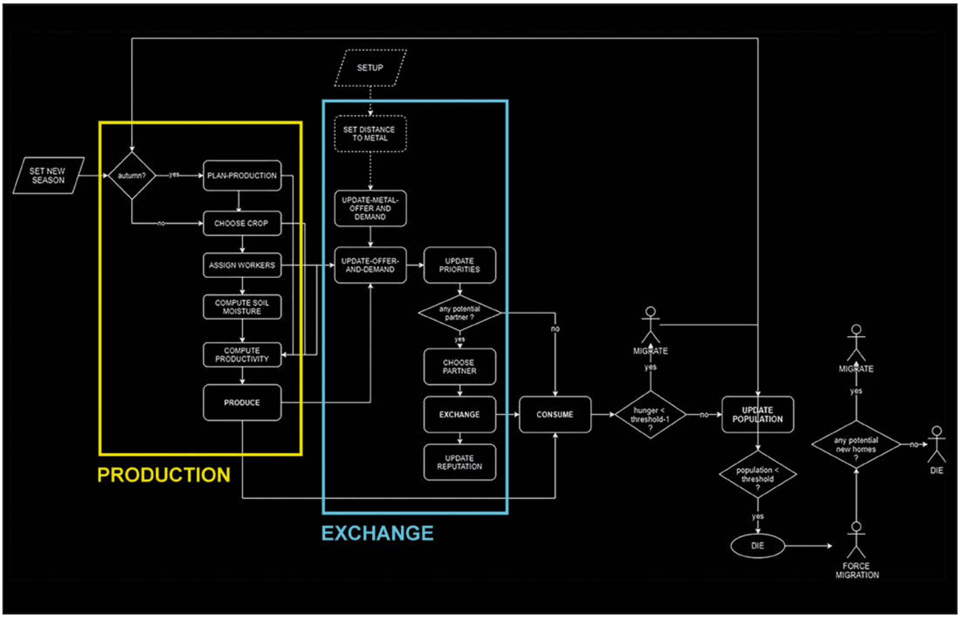


Fig. 2 – Flowchart of a full cycle in AMPBV simulator.

assigned specific attributes related to their functionalities in the simulation. Patches in particular have a set of attributes which were defined according to source data:

– high spatial resolution climate maps in raster format, as a reference for seasonal precipitation and temperatures (Fordham *et al.* 2017);
– contemporary regional pedological maps;
– post-processed Digital Terrain Model (DTM);
– archaeological and botanical data;
– paleo-hydrographic reconstruction based on geological analysis (lastly Balista 2018).

The system behavior (agent choices, alteration of global variables), affects the virtual landscape transformation, thus the patches attributes.

## 3. Cultivating a landscape of virtual patches

Each cycle, patches go through a seasonal update in which new local temperature and precipitation values are set. As a first step in the production process, the sites define their own catchment area by occupying the space needed, for resource exploitation, namely for grain cultivation. To attain a good production, cultivated patches need a high productivity, which is expressed as an attribute. Each patch productivity depends directly on some key local variables:

– Workers, the sites employed manpower.

– Soil fertility, a value randomly assigned to each patch at the start of the simulation that decreases each cycle with land use.

– Soil moisture.

– Local temperature.

– The crop type cultivated on the patch (patch attribute). Agents pick the most suitable species according to the current season and an estimate of soil moisture, the latter depending on both current and previous soil moisture values.

Except for workers, calculated accordingly to the number of inhabitants and the number of cultivated patches of a site, the mentioned variables are directly or indirectly related to climate. An attribute particularly sensitive to climatic variations is soil moisture, which has a fundamental role in the production process, being also involved in the agents predictivity and adaptivity (in the choice of the cereal species to grow) (Burigana, De Guio 2022). Local precipitation has a different impact on a patch soil moisture depending on local soil texture class. The soil textures were extracted from contemporary data, by merging regional soil maps of Veneto and Lombardia into a unified raster image. The regional maps soil information refer to the first meter in depth from the current ground level. Although we know that the surface and to some extent the composition of the soil has certainly changed after more than 3000 years of human activity, it was deemed acceptable to use contemporary data. Indeed, in several archaeological areas investigated and excavated in recent years, Bronze Age stratigraphic units were found to be already exposed at the surface, which is mainly due to the repeated plowing of mechanized agricultural activity. Average values of field capacity, saturation point and capillary fringe thickness were derived from the soil texture data as key-parameters for calculating soil moisture through a very simplified water balance formula:

Soil Moisture = precipitation + groundwater – evapotranspiration

in which groundwater (considering a depth of 1 m and an extent of 1 ha) is the sum of the water in the saturation zone, whereas the water in the capillary fringe (half the saturation point plus half the field capacity local values) and evapotranspiration is calculated according to Hargraves (Hargraves, Samani 1982, 1985) as:

$$ET0\ (mm\ d\text{-}1) = 0{,}0023\ R0\ (T+17{,}8)\ \Delta T\ 0{,}5$$

General precipitation and temperatures, integrated into the model as global variables (globals), are the outcome of a random draw at the beginning of each new cycle (taking into account a seasonal reference value).

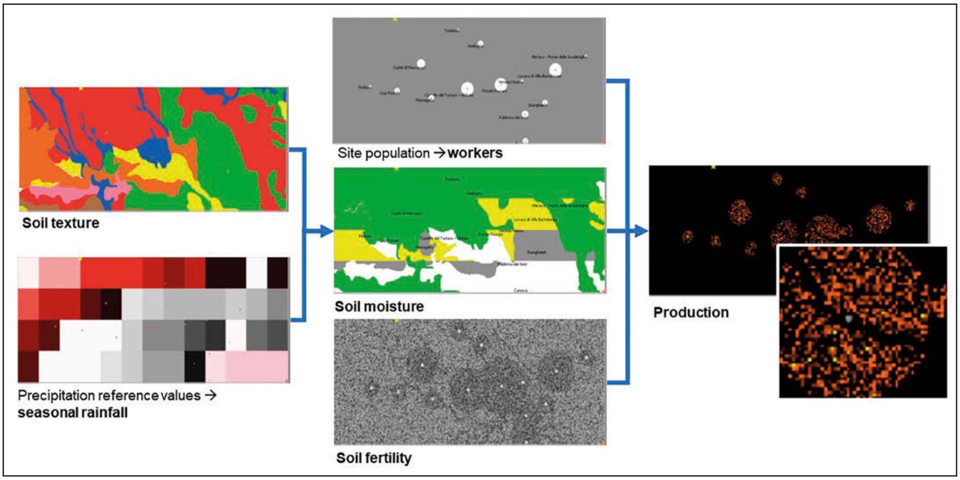


Fig. 3 – Information layers involved in the agricultural production process.

The resulting value is subsequently transmitted to each patch and adjusted according to the local climate zone. Both the reference values and the spatial distribution of climatic zones are derived from the seasonal climate maps, implemented as a georeferenced source data by means of Netlogo GIS extension. Soil moisture (along with the other parameters mentioned above) impacts each cultivated patch production differently, depending on the compatibility of the cultivated species. As a result of the whole production process, a new information level emerges (Fig. 3), working as a sort of resource map in which the sites can convert their cells production in expendable calories for their population.

## 4. Weaving link landscapes

Archaeological record suggests that, in addition to local production, Terramare communities were involved in economic and political relations between sites (intra-polity relations), as well as with other polities (inter-polity relations), in which they exchanged food, but also raw material, handicraft and a variety of other goods. We should assume that in many cases man labor was also a term of trade, being employed massively both in field work and in the construction of large structures and infrastructures (De Guio *et al.* 2015). Since it is likely that the settlements also relied on profitable connections (which may have been crucial at some point) for their survival, a schematic representation of the exchanges between sites has been attempted. In modelling a prediction of how sites choose to trade (and with whom they choose to trade), we took into account both adaptive behaviour of agents in assessing travel costs and political-economic influences based on past trade. Both of these aspects were represented in the AMPBV simulator in the form of networks.

### 4.1 *Travel cost assessments in the connective network*

To simulate movement cost in a physical environment we created a regular network of links (connective links, Fig. 4) georeferenced to our reference map data. Each of these links has an attribute (weight) whose value depends on the local landscape attributes, meaning spatially located features facilitating or hindering movement. Having considered, among these, the terrain slope (although in the lowlands it is not such an impactful factor on movement as in other contexts) we processed our DTM source image to get rid of the most evident "background noise" of modern elements, such as roads, canals, visible straight tracks, and also the present course of the Adige River. The weight of the connective links is calculated as the product of slope friction (quantified

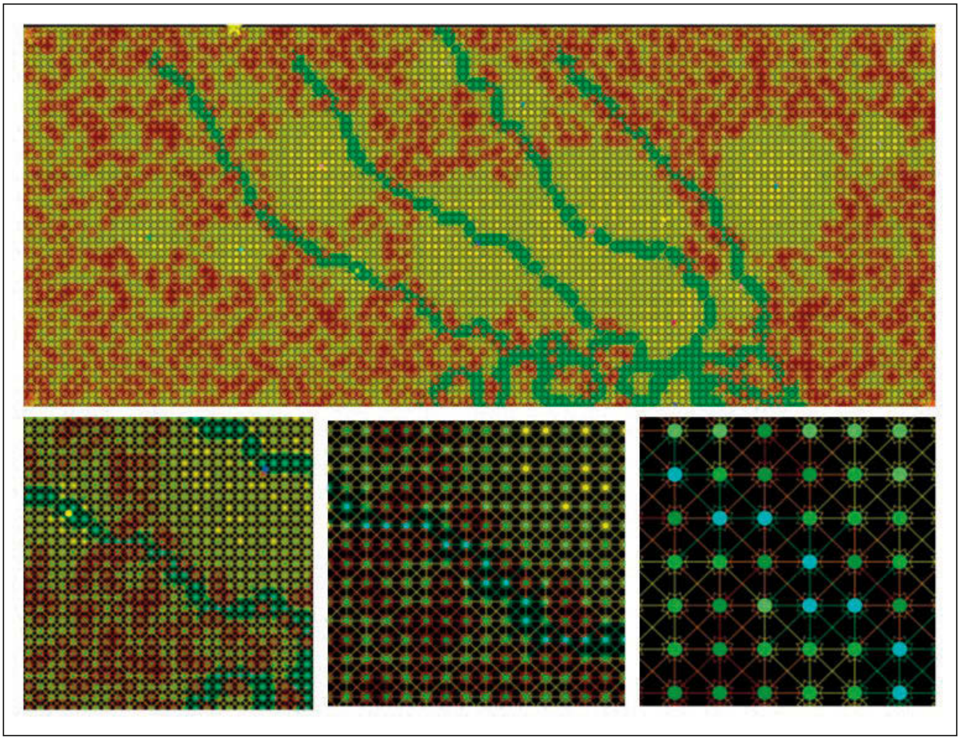

Fig. 4 – Multi-scale visualization of the connective links network.

as metabolic energy cost of walking (CW), according to Minetti *et al.* 2002) and the PAR (Physical Activity Rate, calculated as the ratio of energy cost to basal metabolic rate, see Vaz *et al.* 2005) estimated for human movement in different landscape types, including water:

Connective link weight = terrain type PAR * slope CW

Water patches play an ambivalent role, as rivers require a significant amount of energy to cross but, on the other end, they can be useful navigable waterways. To reconstruct the protohistoric rivers we used both the paleo-hydrological maps and remote imagery, in which we observed soilmarks and cropmarks spatially associated with the coeval settlements.

Two kinds of locations that certainly require a more intensive activity to traverse are forests and muddy grounds. In the simulator, muddy patches are identified as the cells with the highest values of soil moisture. As for forests, although significantly reduced by the end of the Late Bronze Age (Cremaschi 2017), they but still occupied a significant amount of space, especially outside the sites closest catchment areas. We have not yet attempted a precise reconstruction of the forest cover; forest patches are assigned randomly during the setup procedure, according to a percentage set by the user (so far, we tested considering a 40%). Unlike river locations and land elevations, forest cover and muddy soils in AMPBV simulator are characteristics that can change over time depending on the behavior of the system. Both land use and climatic variations, in fact, can transform the patches, which can take on label such as “mud”, “grass” or “forest”. The inter-site weighted distances, and thus the shortest paths connecting each site to the others, are updated each cycle according to Dijkstra algorithm (Dijkstra 1959), implemented in Netlogo extension Network Analysis.

### 4.2 *Building reputation in the relational network*

The last instance of our multilevel environment is an “economic power landscape” (or “mindscape”) where the multitude of relations between sites is represented as a network of “relational links”. The value of these links “reputation” attribute increases proportionally to the number of successful exchanges occurred between the two linked sites. Because reputation is an eligibility criterion (along with weighted distance and supply-demand compatibility) when choosing an exchange partner, sites that have gained more reputation over time have a greater chance of exchanging in the future, thus a greater chance of survival in case of low individual production. Sites in AMPBV simulator can exchange food (cereals), metal and workers. To correlate “goods” so differently commensurable, supply and demand for each are expressed as percentage values, relative to the general availability and necessity within the entire system.

For food, these values depend on the reserve and the local population. There may be a shortage or surplus of workers, depending on the adult population and the number of patches to be cultivated. In the case of the metal, availability is calculated as "purchasing power" taking into account the distance to the Alpine copper mining areas, while demand depends on a "redistribution potential" of the raw material (i.e. reputation with agents located further away from the copper route) and local need (given by the number of inhabitants). Thus, the supply and demand for food and workers depends essentially on the outcome of the production process, while for metal, both physical and economic connectivity is crucial, associated partly with production (which transforms the landscape), but mainly with the outcome of the exchange process.

## 5. Testing and preliminary results

The model is still undergoing tests and technical adjustments, but some preliminary analyses have already been carried out for an initial assessment of the impact of climate on our complex artificial system. In a first survival test, three simulation scenarios were compared by inducing a temporary climate crisis (3 years of drought) at different times (after 5, 20 and 35 years from the start). In general, soil moisture certainly emerges as a factor that is very sensitive to climatic fluctuations, but the comparative analysis also revealed other determining factors for polity survival. While inducing climatic stress after only 5 years showed good resilience, with site survival comparable to the simulation without stress, a different situation was recorded in the other two scenarios, where collapse occurs in less than 10 years. This can be explained by a greater vulnerability of the system, given the impoverishment of the soil at a chronologically more advanced stage.

Lower fertility also implies a greater need for productive space: sites see reduced production possibilities at a time of maximum extension of their catchment areas. It is likely that an unexpected climate change had a more critical impact on an area already compromised by intense colonisation. Moreover, it is possible that, with the local production crisis, the survival of the sites depended more on their political-economic ties. Further analyses, at a more advanced stage of experimentation, will hopefully yield more results. The data collected so far, in any case, suggest the importance of space and landscape representation in its complexity as both a physical and social element. ABM allows us to observe the dynamic evolution of a multifactorial and multi-informative environment, but also to understand the evolution of its different constituent elements and their interaction with the active agents of the system.

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ABSTRACT

The paper illustrates the creation and integration of the environment as a multilevel landscape in AMPBV Simulator, a spatial Agent-Based Model (ABM) developed in NetLogo programming language. The model was conceived with the aim of investigating, through a simulative approach, the events and the circumstances (both anthropic and environmental) that presumably led, between the end of the Late Bronze Age, in the $12^{th}$ cent. BC, and the beginning of the Final Bronze Age, the protohistoric communities of the Southern Verona plain (known as the Northern Terramare polity) from a climatic phase of maximum development and articulation to an anti-climatic phase of sudden collapse. The study context is an interesting application for an investigation through ABM, both because of the complexity of the case scenario, in which several interrelated actors and factors must have played an important role, and because of the availability of a number of geographical and archaeological data providing both a term of comparison and an excellent information base. With the development of an artificial environment and by modeling processes potentially critical for the fate of the Terramare system, the aim is, on the one hand, to give such a complex study case a new tool for historical analysis and, on the other hand, to experiment Agent-Based Modeling and assess its potential as a methodology for archaeological investigation in the Po Plain.

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# A PREDICTIVE MODEL TO INVESTIGATE THE AGRO-PASTORAL EXPLOITATION OF ANCIENT LANDSCAPES

## 1. Introduction

The purpose of this paper is to present a predictive model – created inside the software ArcMap using FAO's "Land Evaluation" techniques (FAO 1976) – able to identify, in a landscape, the most suitable area for the agro-pastoral exploitation. Thanks to this model it is possible to carry out a series of analyses capable of reconstructing the landscape exploited by a settlement and to predict both its animal and plant production as well as the maximum sustainable demography of the site. Before proceeding with the technical explanation of the proposed methodology, the approach – defined as "agro-economistic" (Sotgia 2021) – will be framed within the archaeological theoretical reflection.

Once the agro-pastoral model's genesis is illustrated, its application on a case study (the Final Bronze age settlements of *Ager Tarquiniorum*) extracted from a PhD research on the primary economy of protohistoric communities of Southern Etruria (Sotgia 2023) will be shown. However, the model created can also be applied to other cultural and chronological contexts with very few modifications, as underlined in the final notes that conclude the text.

## 2. Theoretical background

Studies about agro-pastoral production can be found in numerous researches covering all chronological periods analyzed by the archaeological discipline. That is because it is very useful to focus on this theme to make interesting historical reconstructions of the actions of ancient communities. The exploitation of landscape resources has in fact always been the main type of relationship between humans and the environment in which they live. Agriculture represents, moreover, one of the most complex levels of these relations and especially for protohistoric communities for which it is the most evident sign of landscape transformation.

This approach can be found in the works of Clarke's Palaeoeconomy (Clarke 1952) and the Cambridge School of Higgs and Vita-Finzi (Higgs 1975), as well as in some interpretations of Processual archeology about the key role of environment. Moreover, the choice to focus on the forms of agro-pastoral exploitation is due to the belief, derived from Marxist archaeology (McGuire 2002), that by examining the economic components of a society it is also possible to understand its social and political aspects.

Especially, if we consider – as in this case for the Protohistory – that political power was based above all on the administration of primary goods by the elites – as theorized by T. Earle (2015) with his concept of bottleneck, or vice-versa from the community management of these specific goods by the entire community, as pointed out by Hardt and Negri (2009) in their work on the commons.

## 3. Model creation

To simplify and speed up the analysis, a predictive model was therefore created, capable of identifying the most suitable areas of a landscape and a related ArcGIS tool was developed to calculate the various quantitative aspects connected to this production. The agro-pastoral model was obtained by applying to the landscape the modern "Land Evaluation". This method aims to quantify the suitability of a land for agro-pastoral exploitation with a system of descendant quality classes generated through the analysis of some environmental factors, fundamental for agricultural and pastoral practices. These factors are analysed basing both on the specific needs of the plants cultivated and of the animal species and also on the degree of development of the agro-pastoral techniques and knowledge of the communities examined. To obtain this kind of information and translate this technique in an archaeological perspective (as proposed by Van Joolen 2003 and Goodchild 2007), data coming from survey and excavation were considered: coaring, pollen diagrams, palaeobotanical and archaeozoological remains, as well as studies on premodern agricultural techniques and informations from Latin agronomists (Columella, Pliny, Varro, etc.).

In the landscape, indicators of suitability relating to agricultural exploitation are clearly visible, while pastoral exploitation can usually be derived only from the altitude of and the presence of water in the areas (Veenman 2002, 271). Therefore, initially were defined the most suitable areas for cultivation and only later a portion of these was assigned to the pastures. The model illustrated is related to the Final Bronze Age system and it is characterized by the cultivation of wheat, olive, vine, and legumes as well as to the breeding of goats, cattle, and pigs. The analysis was carried out within a GIS using various tools for the creation of raster maps formed by cells, each of which reported the degree (from 1 poor to 10 optimal) of agro-pastoral suitability relating to the various factors considered.

The following factors were examined:

– The slope of the land, as it affects productivity.
– The altitude (with relative maximum and minimum temperatures attested), which acts on the physiological activity and on the regulation of the development of the flora.

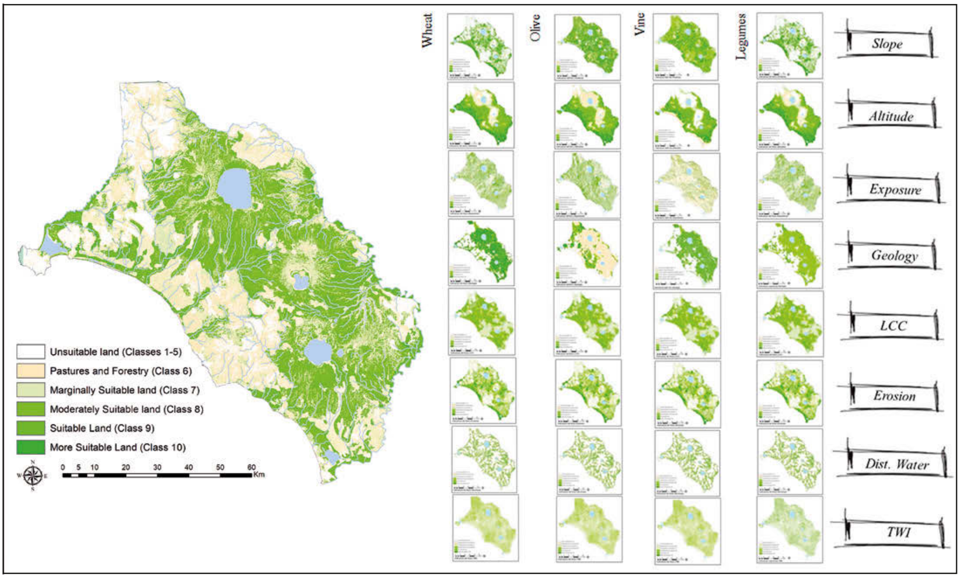



Fig. 1 – Definitive agro-pastoral convenience land model and single factorial maps considered.

– The exposure to sunlight, necessary for the fundamental photosynthesis of plants.
– The geological component of the soil considered both in terms of physic-chemical properties suitable for different crops, and in terms of easy workability of the soil.
– The land propensity/capability for agro-forestry-pastoral production without degradation.
– The distance from the water resource indispensable for the life of every plant organism.
– The presence of water in the soil calculated by the Topographical Wetness Index (Sørensen *et al.* 2006).
– The effect of the erosive phenomenon on the landscape.

All the factors were initially considered autonomously, through the creation of convenience maps (Fig. 1), and later considered all together through a particular multi-criteria analysis: the Analytical Hierarchy Process. In the next lines, the various steps taken to obtain the definitive agro-pastoral model will be generally illustrated, while in Figs. 2-3 the detailed values relating to the different plant species are reported.

Regarding the geology of the soils, after digitizing manually the geological map from one to five million of the area, and converting the polygon to raster,

| | Wheat | Olive | Vine | Legumes |
|---|---|---|---|---|
| **Slope** | | | | |
| *Analytic Hierarchy Process* | 17 | 18 | 18 | 15 |
| 0 – 1 % | 10 | 1 | 1 | 10 |
| 1 – 2 % | | | 10 | |
| 2 – 8 % | 10 | 10 | 9 | 10 |
| 8 – 13 % | 7 | 10 | 8 | 7 |
| 13 – 25 % | 5 | 10 | 7 | 5 |
| 25 – 35 % | 2 | 6 | 7 | 2 |
| > 35 % | 1 | | 1 | 1 |
| > 55 % | | 1 | | |
| **Altitude** | | | | |
| *Analytic Hierarchy Process* | 7 | 10 | 4 | 3 |
| 0 – 33 m | 10 | 10 | 6 | 10 |
| 33 – 100 m | 10 | 10 | 10 | 10 |
| 100 – 200 m | 9 | 9 | 9 | 9 |
| 200 – 300 m | 8 | 8 | 8 | 8 |
| 300 – 400 m | 7 | 7 | 7 | 7 |
| 400 – 500 m | 6 | 6 | 1 | 6 |
| 500 – 600 m | 5 | 6 | | 5 |
| 600 – 700 m | 4 | 6 | | 4 |
| 700 – 800 m | 3 | 1 | | 3 |
| 800 – 900 m | 2 | | | 2 |
| 900 – 1000 m | 1 | | | 1 |
| **Exposure** | | | | |
| *Analytic Hierarchy Process* | 7 | 9 | 9 | 6 |
| Nord | 1 | 6 | 10 | 1 |
| Nord-Est | 6 | 1 | 10 | 6 |
| Est | 10 | 1 | 6 | 10 |
| Sud - Est | 10 | 1 | 6 | 10 |
| Sud | 10 | 6 | 6 | 10 |
| Sud-Ovest | 6 | 10 | 1 | 6 |
| Ovest | 1 | 10 | 1 | 1 |
| Nord-Ovest | 1 | 10 | 1 | 1 |
| **Geology** | | | | |
| *Anlytic Hierarchy Process* | 31 | 29 | 27 | 34 |
| Alluvial Deposits | 10 | 5 | 7 | 8 |
| Travertines | 4 | 10 | 4 | 4 |
| Lavas | 10 | 6 | 10 | 8 |
| Clay | 8 | 8 | 8 | 10 |
| Limestones | 5 | 10 | 5 | 10 |
| Sands | 2 | 6 | 10 | 2 |
| Marlstones | 8 | 10 | 8 | 10 |
| Sandstones | 2 | 5 | 2 | 5 |
| Conglomerati | 5 | 5 | 5 | 5 |
| Conglomerates | 5 | 8 | 5 | 5 |
| Clastic sediments | 2 | 2 | 2 | 2 |
| **Land Capability Classification** | | | | |
| *Analytic Hierarchy Process* | 29 | 24 | 22 | 29 |
| I | 10 | | | |
| II | 9 | | | |
| III | 8 | | | |
| IV | 7 | | | |
| V | 6 | | | |
| VI | 6 | | | |
| VII | 6 | | | |
| VIII | 1 | | | |

| | Wheat | Olive | Vine | Legumes |
|---|---|---|---|---|
| **Distance from water** | | | | |
| *Analytic Hierarchy Process* | 3 | 4 | 9 | 6 |
| < 100 m | 1 | | | |
| 100-500 m | 10 | | | |
| 500 -1000 m | 6 | | | |
| > 1000 m | 1 | | | |
| **Topographical Wetness Index** | | | | |
| *Analytic Hierarchy Process* | 3 | 4 | 9 | 6 |
| 1-3 | 10 | 10 | 1 | 1 |
| 3-5 | 8 | 8 | 7 | 10 |
| 5-10 | 7 | 7 | 10 | 7 |
| > 10 | 1 | 1 | 1 | 1 |
| **Erosion** | | | | |
| *Analytic Hierarchy Process* | 3 | 2 | 2 | 1 |
| Class I<br>Land with a slope of less than 3% where erosion does not occur | 10 | | | |
| Class II<br>Land with slope between 3% and 10% in which less than 30% of the original surface is eroded. | 8 | | | |
| Class III<br>Land with a slope between 10 and 18% in which more than 30% of the original surface is eroded | 6 | | | |
| Class IV<br>Land with a slope greater than 18% in which the original surface is completely eroded. | 4 | | | |

Figs. 2-3 – Values of agricultural suitability of the individual factors analyzed for the various species considered.

a file with 10 m cells was created with the different types of soils present. Each of these was assigned, with "Reclassify" tools, a score from ten to one according to descendant ability to support the different cultivation as described by the agronomic studies considered. The same procedure was followed to define the soil capacity classes of the landscape. Although this is a contemporary parameter, Land Capability Classification (LCC) was chosen because it considers some physic-chemical data difficult to find elsewhere. It is also underlined that in the last three thousand years the characteristics of the soils must not have changed much. After digitizing the map of the area and creating a raster file with 10 m cells showing this information, a decreasing score was assigned to the classes according to their ability to support agricultural or pastoral activities as proposed by Soil Conservation Service of US Department of Agriculture.

The percentage of slope was calculated for each land of the area, starting from a DEM at 10 m provided by the TINITALY (Tarquini *et al.* 2007) project and using the "Slope" function of ArcGIS. Generally, a slope greater than 30% is not recommended for crops, while a slope of up to 10% is considered optimal. However, in the specific case of the olive tree, too low of a slope is not good as the plant grows well even in soils with a steep slope. Starting from the same DEM at 10 m, the classes of suitability related to the land elevation have been created, through the reclassify function of the GIS subtracting a point every 100 m of altitude to the maximum value of 10. This, because every 100 m of increase in elevation on the mountains, the vegetation periods and blooming plants are delayed by 4 to 6 days.

Concerning exposure to sunlight, ArcGIS provides a whole series of tools that can calculate the terrain orientation automatically. The "Aspect" tool was used and the whole area was divided according to the land exposure. The value of suitability was assigned following the indication of the contemporary agricultural studies that show how the territories facing S get better exposure than the ones facing N. For the distance factor from watercourses, buffers of 100 m, 500 m and 1000 m were generated on these rivers and lake, considering them as the area of "suitability" for agricultural exploitation. The different suitability was considered in this way: to simulate the fact that too much water is harmful to plants, a score of 1 was assigned to the soil inside the first buffer. The highest value was assigned to areas within 500 m and a lower one to those within 1000 m. Finally, the latter buffer was considered the maximum distance for agricultural exploitation.

The humidity degree factor is also linked to water and more precisely to its quantity in the soil. In fact, the agricultural limitations deriving from poor soil drainage are well known. To obtain this factor map, the Topographic Wetness Index of area was calculated by applying the TWI formula (where is the water accumulation and the slope) within the "Raster Calculator" tool. The obtained raster file was then reclassified considering the value of 10 as the threshold beyond which a land is to be considered a wet area. Finally, for the last factor considered, that is the effect of the erosive phenomenon, the risk classes proposed by Davidson *et al.* 1994 have been identified using exclusively the criterion of their slope. Starting from the DEM file, the slopes of the areas have been calculated and through the "Reclassify" tool, they have been grouped into the four classes in Fig. 2.

Clearly, erosion has a negative effect on agriculture since it basically subtracts or alters the land useful for cultivation. In cases of more intense erosion, the removal of portions of land has a faster speed than the sedimentation of the new soil, revealing the underlying bare rock. Starting from the value of 10 for class I, two points have been subtracted from each class as the effect of erosion increased. Once all the factorial maps were completed, they were superimposed, thus considering together all the variables involved in the definition of the most suitable soils for the cultivation. However, since some factors, such as soil type, are more important than others, such as Aspect, a technique was used to weigh each individual factor value: the Analytical Hierarchy Process, as it has already been done in many works on contemporary agriculture (Akinci *et al.* 2013; Ahmed *et al.* 2016).

This technique, developed within the communication sciences, allows to identify the specific weight of each factor within a choice, using comparison scales (like the one by Saaty 1980) between single variables as fully described in Sotgia 2020 and 2021. Through the Analytic Hierarchy Process (AHP), it was possible to obtain the percentage of incidence of the individual factors to use the ArcGIS function of "Weighted Overlay" and obtain the final map through a weighed overlay of the individual factors. Once the most suitable soils for the cultivation of each species were identified, the AHP was applied again, overlapping the factors according to the following scheme: the weight assigned to wheat is 38%, to legumes 29%, to vines 19% and to olive trees 14%. These numbers refer to the attested frequency of each plant species within the archaeobotanical and palynological record (Minniti 2012).

The definitive model is therefore a raster file in which the cells contain the convenience value from 1 to 10 for their exploitation for agricultural purposes. All the cells with a value from one to five are considered unsuitable for agro-pastoral exploitation, the cells with a value of six can be used for woods or as pastures, while the cells from seven to 10 are suitable for agricultural exploitation.

In accordance with the palynological and archaeobotanical data of Southern Etruria, the model can be interpreted as follows: 60% of the class six land was occupied by woods and 40% by pastures.

The agricultural land, on the other hand, housed the following crops: olive groves (14%), vineyards (19%) and fields of wheat and legumes in the remaining 67%. The latter group was further internally subdivided as a rudimentary form of crop rotation was applied. Therefore, of the 67% of the land, 50% was devoted to the cultivation of wheat, 30% to legumes and the remaining 20% was set aside.

## 4. Model use

Once in possession of the agro-pastoral exploitation model of a territory, it can be used to carry out a whole series of important analyses for the historical reconstruction of ancient communities. The agro-pastoral landscape exploited by a settlement can be reconstructed through techniques such as the Bubble Method (Alessandri 2015) or Thiessen Polygons. The extension in hectares of fields and pastures can be individuated and the agro-pastoral system of an inhabited area can be modelled. It is also possible to infer the animal and vegetable production and consequently both the maximum sustainable demography of the settlement and the possible specialization of the site, following one of the many ancient production estimates proposed in the literature[1].

The following paragraph shows the application of this type of analysis to all the settlements present in the Late Bronze Age in the *Ager Tarquiniorum* (Fig. 4). The most important data that can be obtained through the model are the demographic ones, and the graph shows the trend of the population in the area and the number of inhabitants per village during the analysed period (Fig. 5a). Thanks to these data it is possible to characterize historical phenomena – such as the passage from the villages to the early cities ("Protourban Turn", Pacciarelli 2016) – from the point of view of the population involved. Furthermore, it is also possible to reconstruct the communities in detail through the quantification of the primary economy of each settlement, also identifying the existence of specialized sites in certain production.

In this way it will be possible to hypothesize the existence of groupings between sites, such as microsystems or other socio-political typologies, and at the same time any surplus produced (Fig. 5b). In the study area a general phenomenon of concentration of the settlements is attested, with the decrease in the number of sites and the increase of the inhabitants. However, with the passage between FBA1-2 and FB3A there is no massive increase of population, and even falls at the end of the FBA3B. In other words, there was a coherent and organic development of the communities throughout this period with a

[1] In the presented case study the considered vegetable yield is an annual production of 3 quintals of wheat against a *per capita* consumption of 1,82 q. In the total of quintals produced, one sixth was subtracted for sowing the following year and considered a loss of 25% of the product during transformation into flour. Animal yields, on the other hand, were obtained by considering the number of pastures exploited, the different meat production and the percentages of animals slaughtered for each species, in accordance with Minniti 2012,102. The considered annual *per capita* consumption of meat is 18,2 kg.

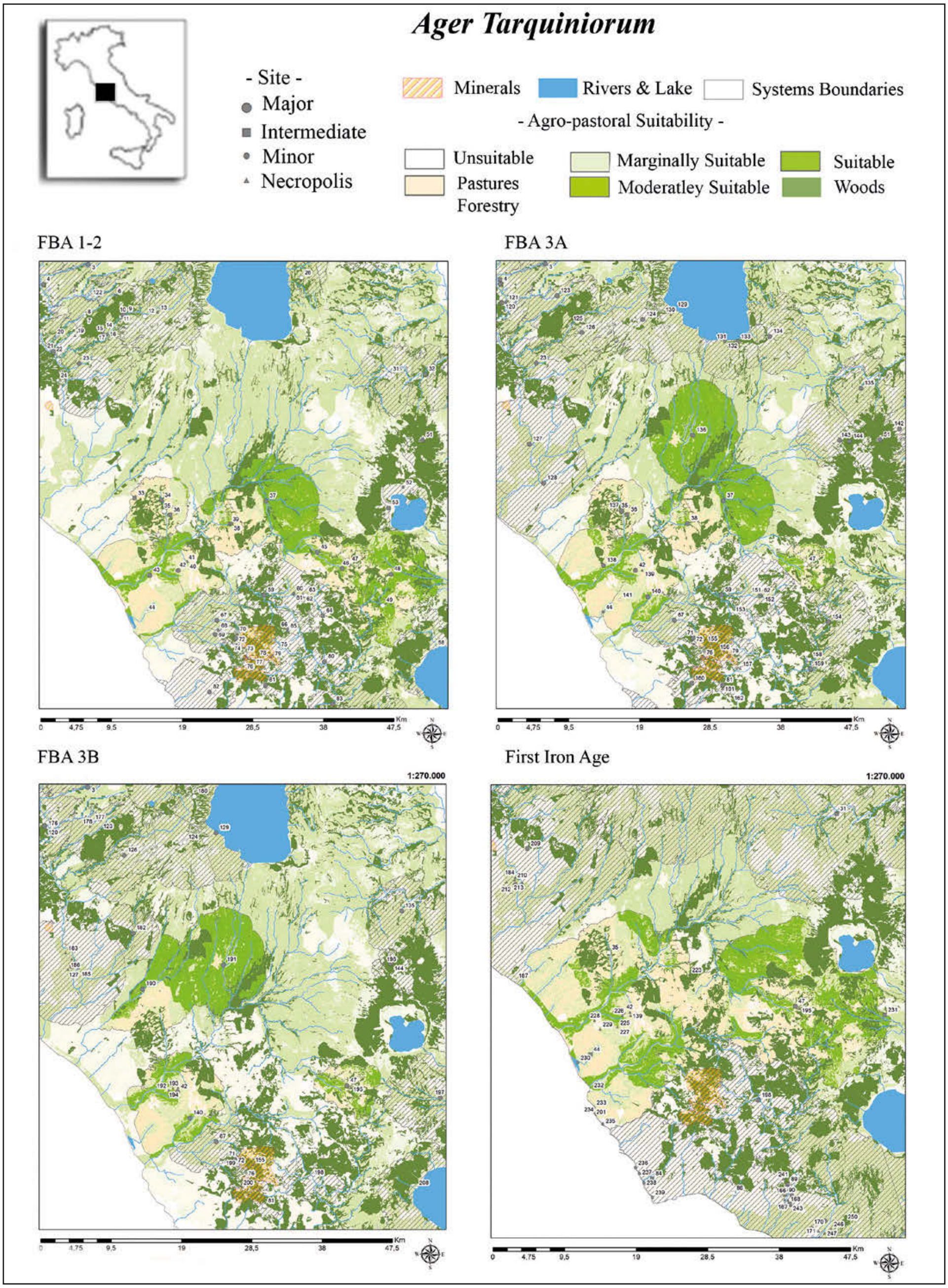
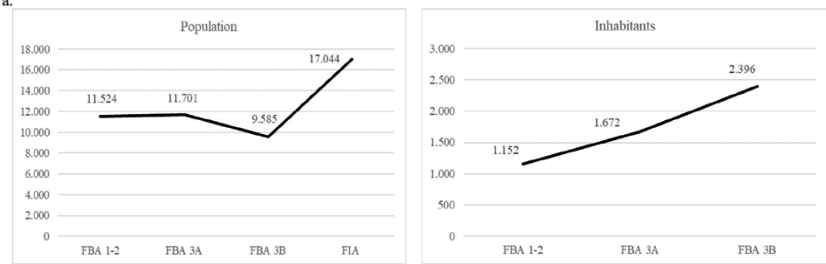



Fig. 4 – The case study of the *Ager Tarquiniorum*.

a.




b.

specialization | Surplus | Not Self-Sufficient

Final Bronze Age 1-2

| ID - Site | | Territory (hectares) | Land Use (hectares and %) | | | | | | People supported | | | Surplus % | Total population | Inhabitants (average) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Woods | % | Pastures | % | Crops | % | Tot. | Veg. yields | An. yields | | | |
| 33 | Poggio Martino | 5.332 | 2.710 | 51 | 539 | 10 | 1.722 | 32 | 835 | 684 | 151 | - | 11.524 | 1.152 |
| 34 | C. Roccaccia | | | | | | | | | | | | | |
| 35 | Ferleta | | | | | | | | | | | | | |
| 36 | Casale Saetto | | | | | | | | | | | | | |
| 37 | Norchia | 10.717 | 3.151 | 29 | 334 | 3 | 6.198 | 58 | 2.700 | 2.463 | 236 | 57 % | | |
| 38 | Torrionaccio | 4.045 | 2.001 | 49 | 515 | 13 | 1.180 | 29 | 599 | 469 | 130 | - | | |
| 42 | Tarquinia | 5.107 | 1.690 | 33 | 356 | 7 | 2.381 | 47 | 1.079 | 946 | 132 | - | | |
| 43 | C. Corneto | 9.739 | 2.904 | 30 | 1.155 | 12 | 4.670 | 48 | 2.192 | 1.856 | 336 | 47 % | | |
| 44 | F. delle Serpi | | | | | | | | | | | | | |
| 45 | Blera | 4.658 | 1.617 | 35 | 301 | 6 | 1.959 | 42 | 890 | 779 | 111 | - | | |
| 46 | il Pontone | 2.107 | 1.051 | 50 | 225 | 11 | 574 | 27 | 287 | 228 | 59 | - | | |
| 47 | San Giuliano | 1.628 | 702 | 43 | 117 | 7 | 574 | 35 | 267 | 228 | 39 | - | | |
| 48 | Monte Sant'Elia | 8.099 | 2.743 | 34 | 211 | 3 | 4.333 | 54 | 1.888 | 1.722 | 166 | 39 % | | |
| 49 | Valle Nobile | 3.471 | 1.150 | 33 | 151 | 4 | 1.788 | 52 | 789 | 710 | 79 | - | | |

Final Bronze Age 3A

| ID - Site | | Territory (hectares) | Land Use (hectares and %) | | | | | | People supported | | | Surplus % | Total population | Inhabitants (average) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Woods | % | Pastures | % | Crops | % | Tot. | Veg. yields | An. yields | | | |
| 136 | R. Respampani | 12.004 | 1.910 | 16 | 48 | 0 | 8.693 | 72 | 3.703 | 3.455 | 248 | 55 % | 11.701 | 1.672 |
| 35 | Ferleta | 4.518 | 2.424 | 54 | 442 | 10 | 1.369 | 30 | 668 | 544 | 123 | - | | |
| 36 | Casale Saetto | | | | | | | | | | | | | |
| 138 | Montarana | 7.658 | 2.340 | 31 | 860 | 11 | 3.621 | 47 | 1.694 | 1.439 | 255 | 1 % | | |
| 44 | F. delle Serpi | | | | | | | | | | | | | |
| 42 | Tarquinia | 8.025 | 2.111 | 26 | 600 | 7 | 4.336 | 54 | 1.951 | 1.723 | 228 | 14 % | | |
| 140 | Pisciarello | | | | | | | | | | | | | |
| 141 | Casale Pacini | | | | | | | | | | | | | |
| 38 | Torrionaccio | 3.737 | 1.849 | 49 | 476 | 13 | 1.086 | 29 | 550 | 431 | 119 | - | | |
| 37 | Norchia | 9.598 | 2.659 | 28 | 317 | 3 | 5.671 | 59 | 2.471 | 2.254 | 217 | 32 % | | |
| 47 | San Giuliano | 3.458 | 1.303 | 38 | 242 | 7 | 1.455 | 42 | 665 | 578 | 86 | - | | |

Final Bronze Age 3B

| ID - Site | | Territory (hectares) | Land Use (hectares and %) | | | | | | People supported | | | Surplus % | Total population | Inhabitants (average) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Woods | % | Pastures | % | Crops | % | Tot. | Veg. yields | An. yields | | | |
| 191 | Tuscania | 12.162 | 2.398 | 18 | 63 | 1 | 8.570 | 70 | 3.655 | 3.406 | 249 | 34 % | 9.585 | 2.396 |
| 190 | C. Formiconcino | 8.617 | 2.197 | 28 | 611 | 7 | 4.754 | 55 | 2.132 | 1.890 | 242 | - | | |
| 42 | Tarquinia | 12.251 | 3.395 | 28 | 986 | 8 | 6.430 | 52 | 2.911 | 2.556 | 356 | 18 % | | |
| 140 | Pisciarello | | | | | | | | | | | | | |
| 47 | S. Giuliano | 4.847 | 1.934 | 40 | 326 | 7 | 1.940 | 40 | 887 | 771 | 116 | - | | |

First Iron Age

| ID - Site | | Territory (hectares) | Land Use (hectares and %) | | | | | | People supported | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Woods | % | Pastures | % | Crops | % | Tot. | Veg. yields | An. yields |
| 42 | Tarquinia | 81.364 | 29.051 | 36 | 6.098 | 7 | 37.414 | 46 | 17.044 | 14.869 | 2.174 |

Fig. 5 – a) The trend of the population in the area and the number of inhabitants per village during the analysed period; b) quantitative analysis of the different territorial systems of the *Ager Tarquniorum*.

territorial system becoming more and more extensive through the reasoned occupation of the most fertile areas. However, it is interesting to note that the increase in the agricultural vocation of the territorial systems does not affect all the main sites: Tarquinia even seems to maintain an articulated productive exploitation of the territory.

Finally, observing the self-sufficiency/surplus indices, the existence of a supra-village mutualistic dimension is emphasized, aimed at avoiding internal competition and guaranteeing the control of this fertile territory. However, with the development in the full phase of the FBA of Tarquinia, this dimension is put into crisis, and competition between systems for controlling the coastal area increases exponentially. The outcome of this competition will lead – in the end – to the affirmation of the protourban city of Tarquinia and to the concentration in it, in the Iron Age, of the communities of the area.

## 5. Final notes

This methodology can also be applied to other cultural and chronological contexts with very few modifications such as the mapping of additional plant and animal species or the addition of further factors (the presence of roads, the distance from market areas, etc.). The operations described have also been automated within a tool for ArcGIS under development (Sotgia 2022). The goal is to make this tool available to allow various scholars to use it in their research contexts. In the end, obviously, like all theoretical models, also the one presented here have a certain rigidity, which can only be smoothed out with a "field check". Pending systematic surveys of the territory to expand the available data and acquire precise geological and environmental information, a preliminary investigation tool has been developed, which is added to our archaeological toolbox, thus allowing more and more complete and detailed historical reconstructions.

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## ABSTRACT

Thanks to the reconstruction of agro-pastoral land use of a territory, it is possible to obtain much information, both of an ecological nature, and about the populations. By the reconstruction of these dimensions of a community it is possible to understand not only the aspects linked to the exploitation of a territory, the subsistence and demography of a given

group, but also more generally the group's social organization itself. With a series of GIS tools, capable of applying the FAO's land evaluation techniques, it has been possible to generate a predictive raster model of the landscape with the degree of agro-pastoral suitability inside each cell. Thanks to this model, the agro-pastoral exploitation of a territory can be simulated, calculating the food production of each settlement, as well as the consequent demography maximum sustainability. Thanks to the identification of specialized productions sites and of settlements capable of producing a 'surplus', or vice versa 'not-self-sufficient', it will be possible to articulate socio-political models, hypothesizing exchange networks or relationships between the different sites. The text illustrates in detail the structure and functioning of the developed model, as well as its applications in the archaeological context of the *Ager Tarquiniorum* during the Final Bronze Age.

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# TESTARE SUL CAMPO LA LEAST COST PATH ANALYSIS: RIFLESSIONI INTORNO AI PAESAGGI DELL'ETÀ DEL BRONZO DELLA SARDEGNA CENTRO-MERIDIONALE (ITALIA)

## 1. Introduzione

Da circa dieci anni il gruppo di ricerca, afferente alla Cattedra di Preistoria e Protostoria dell'Università di Cagliari, formatosi per studiare in un'ottica interdisciplinare il paesaggio archeologico nuragico, ha cercato di portare avanti nuovi metodi per la lettura e l'interpretazione delle dinamiche di insediamento delle comunità dell'età del Bronzo della Sardegna, periodo in cui si può osservare il manifestarsi della civiltà nuragica, tra il Bronzo Medio e la I età del Ferro (dal XVIII al VI sec. BC) (Ugas 2014; Moravetti 2015). In questo contributo è stata condotta un'analisi predittiva con l'obiettivo di chiarire gli aspetti legati al movimento all'interno del rapporto uomo-territorio di età protostorica. L'indagine è stata realizzata in un territorio campione tramite analisi Least-Cost Path (LCPA) effettuate in ambiente GIS; su alcuni dei 35 percorsi risultati è stata poi attuata una campagna di verifica sul campo di alcune direttrici risultanti dalle analisi Least Cost e se ne presentano in questa sede i risultati.

Per definire il paesaggio di pertinenza delle comunità protostoriche dell'area oggetto di studio, si sono prese in considerazione componenti fisiche e documentarie: le caratteristiche geomorfologiche; quelle geologiche, connesse ai depositi derivanti dalle azioni secolari del reticolo idrografico; le emergenze archeologiche, punti di partenza e di arrivo delle direttrici di movimento nello spazio e funzionali alla presa di possesso di un dato territorio. La regione Monte Arci-Nord Marmilla ci è sembrata un caso studio interessante in quanto non vi erano ancora stati effettuati studi specifici di analisi territoriale.

Il settore oggetto di indagine, comprendente gran parte dell'attuale Provincia di Oristano (Sardegna centro-meridionale), è caratterizzato dalla presenza del Monte Arci, vero cuore dell'area indagata, rilievo vulcanico noto nella letteratura archeologica in quanto luogo di origine dell'ossidiana sarda, utilizzata nell'isola, ma anche nell'Europa continentale per tutto il periodo preistorico (Lugliè 2020). La sua attività magmatica ebbe luogo alla fine dell'Era Terziaria, nel Pliocene (3,8-2,6 milioni di anni). Si ha poi la regione storica denominata Alta Marmilla, caratterizzata essenzialmente da sedimenti marini del Miocene inferiore e medio (21-15 milioni di anni). Tale areale, situato ad E del Monte Arci, è contraddistinto da un sistema di colline dalle forme dolci che si raccordano con le forme più ripide tipiche della montagna

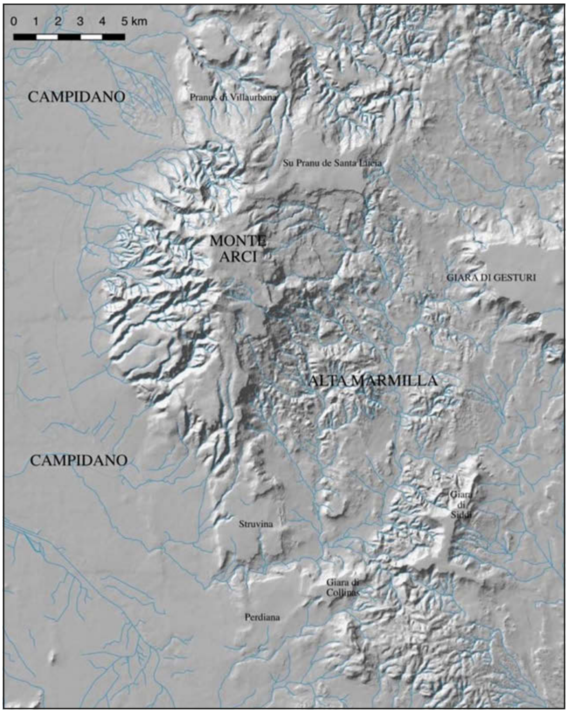


Fig. 1 – Mappa con base hillshade e reticolo idrografico dell'area di studio.

Fig. 2 – Vista dalle colline dell'Alta Marmilla in cui è situato il Nuraghe Procilis-Gonnostramatza verso Mogoro; sullo sfondo il Campidano.

e con le caratteristiche "giare", altipiani basaltici di diversa estensione dal caratteristico profilo tabulare. Ad O, infine, una parte della pianura del Campidano, nel settore compreso tra Mogoro e Oristano, caratterizzata da un ambiente pianeggiante o con pendenze variabili, confinante con il Monte Arci. Con la valutazione di questi parametri, senz'altro implementabili in futuro, è stato possibile avanzare ipotesi sulle tendenze generali del movimento attraverso questo territorio (Figg. 1-2).

## 2. Metodologia

Il record archeologico dell'età del Bronzo in quest'area mostra numerosissime manifestazioni monumentali, spesso di imponenti dimensioni, quali nuraghi semplici, caratterizzati da singole torri, nuraghi di tipo complesso, costituiti da torri plurime, a volte in connessione con coeve strutture capannicole, nelle più svariate forme e configurazioni (dal Bronzo Medio agli inizi del Bronzo Finale) (Lilliu 1982; Depalmas 2015). Abbiamo inoltre villaggi sviluppatisi anche in fasi successive (Bronzo Finale-I Ferro) attorno a nuraghi semplici o complessi, ma anche ubicati in aree senza nuraghe di riferimento. Sono poi presenti varie tombe collettive di carattere monumentale, dette tombe di giganti (Bronzo Medio-Recente). Si hanno, infine, altre strutture di età nuragica, quali pozzi e fonti di carattere sacro, tradizionalmente legate a culti che prevedevano l'utilizzo delle acque, presenti anche all'interno di santuari (Bronzo Finale-I Ferro).

La strategia utilizzata per questo tipo di analisi è stata quella di collegare i siti ai margini dell'area di studio al fine di valutare, attraversando l'area con i percorsi Least Cost, la vicinanza dei siti ai tratti risultanti dall'analisi. Scopo di questa applicazione è stato quello di individuare l'insistenza di siti nuragici in punti strategici o aree di passaggio presenti nell'area indagata, in modo da mettere in relazione le strutture nuragiche con le principali vie di movimento attraverso il territorio oggetto di studio. Lo strumento principale per realizzare questa applicazione in ambiente GIS è il modello della superficie dei costi. Calibrare un buon sistema di valori all'interno di un modello di superficie di costo è a nostro avviso la chiave per un'analisi che sia quanto più rapportabile al comportamento di un gruppo umano nei confronti della mobilità in un territorio campione. L'analisi si basa, dunque, su un modello di costo (Fig. 3) creato grazie a strumenti geografici digitali reperibili nelle raccolte cartografiche della Regione Sardegna (http://www.sardegnageoportale.it): i database relativi alle caratteristiche geologiche dell'area, estrapolati dal database multiprecisione (DBMP), e il DTM - Modello Digitale del Terreno, la rappresentazione della distribuzione delle curve di livello e dei punti quotati del territorio in formato digitale. I siti, oggetto di ricognizione, sono stati implementati in un database e rappresentati nel GIS mediante un

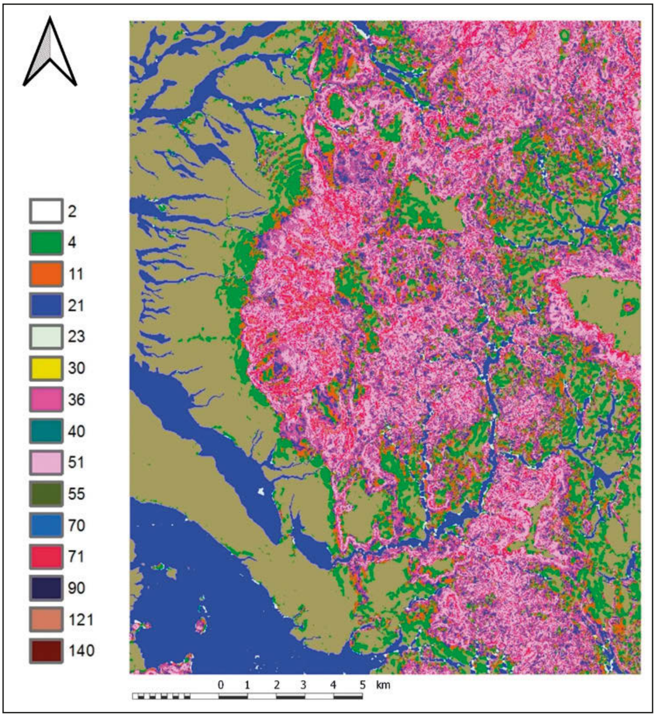


Fig. 3 – Cost Surface Model utilizzato per le analisi GIS e relativa scala di valori.

tematismo vettoriale puntuale relativo ai siti oggetto di studio. Si è creato un modello di costo (Wheatley, Gillings 2002; Conolly, Lake 2006) finalizzato all'analisi dei costi di percorrenza che ha tenuto conto della somma di queste componenti:

– DTM passo 10 m. Dal DTM si è poi generata la carta delle pendenze, mediante la funzione slope. I valori relativi alla pendenza sono stati poi riclassificati (reclass) in base ai vari gradi di pendenza.
– Idrografia. Il reticolo idrografico è stato preso in considerazione mediante gli areali, estrapolati dalla carta geologica, caratterizzati dai sedimenti alluvionali prodotti dai corsi d'acqua della zona campione.

A questi è stato assegnato un valore all'interno del modello di costi di percorrenza; sono poi confluiti in un unico shape poli-areale (merge) e poi convertiti in formato raster (vector to raster) con l'assegnazione (reclass) del costo di percorrenza. Ai sedimenti alluvionali sono stati assegnati valori equivalenti all'intervallo di pendenza tra 10 e 14 gradi. Nel nostro modello queste zone sono state considerate con un peso rilevante nella scala di difficoltà di percorrenza, perché soggette a inondazioni e sicuramente evitate nelle scelte insediamentali a carattere stanziale (Cabras 2018). Molti di questi settori risultano coincidenti con fondi di vallate, generalmente evitati nei sistemi di viabilità basata sulle forme del terreno, proprio a causa del rischio idrogeologico.

I raster relativi alla pendenza e ai sedimenti alluvionali, riclassificati secondo i valori assegnati, sono stati semplicemente sommati mediante map algebra (raster calculator). Il modello di costo (cost surface model) è scaturito dunque dalla somma di queste due variabili (cfr. ad es. Van Leusen 2002; Pecere 2006; Fabrega Álvarez, Parcero Oubiña 2007; Llobera, Fábrega-Álvarez, Parcero-Oubiña 2011). Gli algoritmi di tipologia Cost permettono di calcolare il costo energetico speso da un individuo per muoversi nello spazio. Il modello ha costituito la base per considerare le direttrici di minimo sforzo che, collegando rilevanti insediamenti anche tra i più esterni all'areale di studio, hanno permesso di osservare l'attraversamento dell'area oggetto di studio e conseguentemente di valutare il rapporto con il record monumentale. Per tale analisi, tutti gli insediamenti di età nuragica sono stati considerati come contemporaneamente esistenti tra il Bronzo Medio e il Bronzo Recente.

La scelta dei collegamenti tra siti è stata orientata su questi obiettivi: valutare quali potevano essere i percorsi a minor costo di percorrenza per collegare siti in cui doveva essere possibile attraversare le aree a quote maggiori del massiccio del Monte Arci, viste le ovvie difficoltà di percorrenza a causa delle caratteristiche orografiche; attraversare l'area di studio nelle varie direzioni cardinali; valutare se i siti ubicati sui bordi delle giare avessero una relazione coi percorsi a minimo costo di percorrenza.

Un'ulteriore fase del lavoro è consistita nel verificare sul campo alcuni di questi percorsi tramite percorrenza pedissequa sul campo di parti o di interi percorsi (Fig. 4). Il team sul campo ha verificato la possibilità della percorrenza che attualmente era ovviamente viziata dagli elementi che condizionano la mobilità nel territorio, quali recinzioni, vegetazione e proprietà. Sono state valutate la possibilità, o meno, della percorrenza, nonché il suo grado di difficoltà sulla base di 4 classi: 4) impossibile; 3) difficile ma possibile; 2) semplice ma con importante dispendio energetico; 1) semplice. Per tutte queste classi è stata ricercata la possibilità di nuovi rinvenimenti (ceramici, litici, strutture?) con la disposizione della squadra di ricognitori in forma sparsa lungo il settore territoriale adiacente al percorso risultante dalle analisi GIS.

## 3. Risultati

Come primo aspetto si commentano i risultati della fase di analisi tramite GIS: il reticolo risultante di 35 percorsi (Fig. 4) appare più rarefatto in prossimità delle quote e delle pendenze superiori, in prossimità dell'Arci. Il

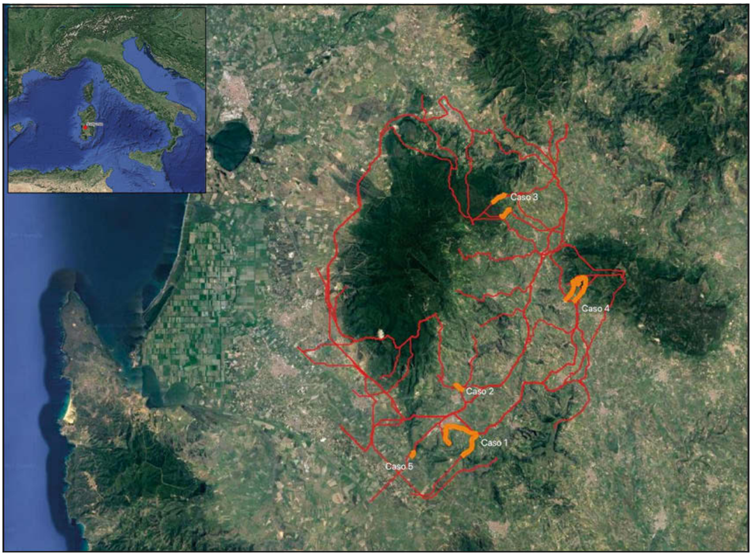


Fig. 4 – Mappa dell'area di studio con i percorsi risultanti e l'ubicazione dei 5 casi verificati sul campo.

percorso è più semplice, invece, in prossimità delle valli che dal Campidano conducono verso le aree interne della zona di studio. I percorsi evitano la scalata ai pianori con dislivelli troppo accentuati privilegiando a N l'altopiano di Santa Lucia (Usellus), a S quelli di Perdiana e Struvina (Mogoro), ad E la Giara (cd. di Gesturi). Nelle aree collinari i percorsi seguono l'andamento delle fasce più dolci. Per quanto riguarda l'attraversamento del Monte Arci, si è notato come si privilegino le località vicine alle strette valli o canaloni più agevolmente percorribili. La tendenza che sembra essere predominante è quella che in prossimità di queste ultime i monumenti controllino dall'alto, e visivamente, i percorsi e le aree ad essi limitrofe spesso tramite coppie o terne di nuraghi semplici o anche da gruppi di nuraghi complessi. L'ubicazione dei monumenti allo sbocco delle valli di penetrazione alla piana campidanese non sembra un fattore sistematico ma è sicuramente ricorrente.

Per quanto riguarda la parte meridionale dell'area di studio, risaltano casistiche interessanti: è infatti sorprendente il numero di monumenti che vengono quasi a contatto dei percorsi accompagnandone lo sviluppo. Si nota un modello di comportamento abbastanza frequente, con certi siti vicini ai percorsi e altri che li controllano dai punti alti. Un'altra casistica interessante è quella dei monumenti ubicati in prossimità degli accessi ai tavolati basaltici (giare) o che fungono quasi da checkpoint lungo i versanti più propizi per l'accesso. È il caso del Nuraghe Mialis e del sito pluristratificato di Santa

Fig. 5 – Il Nuraghe Santa Lucia di Usellus, lungo uno dei percorsi indagati.

Lucia, entrambi presso Usellus, del Nuraghe Cuccurada di Mogoro nonché di diversi siti presso la giara di Gesturi, siti che sono stati oggetto della verifica sul campo.

Per quanto riguarda, invece, la fase sperimentale sul campo, l'analisi ha fornito interessanti spunti di riflessione. Il primo caso di studio è stato condotto nella piana del rio Mannu/Mogoro presso Gonnostramatza e Mogoro. Il grado medio è stato di 2,5, considerato facile in termini di dispendio energetico, ma non molto semplice per via della vegetazione e delle recinzioni. Qui è stato possibile rinvenire resti murari riconducibili ad un probabile nuraghe oggi pesantemente rimaneggiato (Loc. Turriga presso Gonnostramatza). Il rapporto tra il percorso LCPA e un nuovo sito continuerebbe a suggerire lo stretto rapporto tra mobilità e insediamento per questa regione. Si è dunque evidenziata una sostanziale identità tra il percorso ipotizzato e quello realmente percorribile.

Il secondo caso, applicato su una zona pianeggiante/leggermente ondulata nei pressi di Masullas, ha presentato una percorrenza molto semplice ma la difficoltà nella ricerca di un punto di guado lungo un corso d'acqua. I punti di guado sono un argomento di interesse in quanto è difficile trovare ponti edificati di età nuragica (Foschi Nieddu 2008; Serra 2008), che quindi erano probabilmente realizzati in strutture lignee (grado 2,5). Anche in questo caso il percorso non si discostava di tanto da quello risultante dalle analisi GIS.

Nel terzo caso sono stati analizzati due percorsi, a breve distanza, ed è il caso studio dedicato alle aree di contatto con i bordi degli altipiani basaltici. Il primo percorso (grado 3), presso la Scala Argentu, ha permesso di raggiungere l'altopiano di Santa Lucia, seppur con importante dispendio fisico, dimostrando la possibilità di accedere al pianoro mediante il percorso risultato dalle LCPA. Il secondo percorso di questo terzo caso è stato portato avanti nei pressi dell'area archeologica di Santa Lucia-Usellus (Fig. 5), nei pressi dell'insediamento di età romana *Colonia Iulia Uselis* (Usai, Zucca 1986), evidenziando un dispendio energetico importante ma una percorrenza sostanzialmente facile (grado 2,5), che ricalca sostanzialmente il percorso ipotizzato dal software.

Il quarto caso, portato avanti nei pressi dell'area archeologica di Bruncu Suergiu-Gonnosnò ha evidenziato grado 4, ovvero impossibilità di raggiungere l'altopiano lungo la LCPA, ma solo attraverso la strada moderna, che passa poco più ad O sfruttando gradualmente l'andamento delle curve di livello. Peraltro, tale impossibilità è probabilmente voluta dalle popolazioni che frequentavano il sito, costituendo di per sé stessa un elemento di difesa del sito dell'età del Bronzo. Il quinto caso, presso Cuccurada-Mogoro, ha evidenziato grado 3 in quanto la percorrenza è risultata non troppo difficile in termini di dispendio energetico, ma attualmente difficoltosa a causa della vegetazione e delle recinzioni; tuttavia la strada antecedente la rete viaria moderna, utilizzata sino al XX secolo, ha seguito esattamente il percorso di prova.

## 4. Conclusioni

Sulle varie LCPA indagate è stato possibile valutare la percorribilità in maniera positiva, anche in corrispondenza di pendenze impegnative per il team che le percorreva. Nella nostra opinione, diversi sentieri si sarebbero potuti percorrere, seppur con grande impegno, anche mediante un carro trainato da forza animale. Un'analisi di questo tipo aiuta certamente a stimolare il ragionamento sulle tipologie di mobilità che potevano mettersi in atto nell'antichità con carri trainati da animali, individui che si muovevano a piedi, individui che montavano direttamente un animale, e sulle possibilità di utilizzare diverse modalità di trasporto in relazione all'obiettivo del movimento e alle diverse aree e conformazioni orografiche del territorio, condizionamenti importanti, seppur non limitanti, per ogni attività.

Infine, non è stato possibile seguire il percorso a Bruncu Suergiu (caso 4, Fig. 4). Un aspetto che ci sembra importante segnalare, riguardo a questo caso, è che le LCPA sembrano affrontare direttamente la scalata di tratti a forte pendenza o anche con dei salti di quota notevoli, talvolta irraggiungibili se non tramite una scalata, al fine di limitare il dispendio energetico rispetto alla ricerca di tratti più agevoli, anche distanti che, con pendenze più dolci, potrebbero favorire il raggiungimento dell'altopiano. Questo comportamento si rileva infatti nei tratti relativi alla scalata sugli altopiani basaltici e sembrerebbe potersi ricondurre maggiormente ad una percorrenza del territorio a piedi, con la possibilità di scalata/arrampicata da parte dell'individuo che attraversa il tratto interessato. Il percorso alternativo alla ricerca di punti di accesso più agevoli potrebbe essere più adeguato alla percorrenza carrabile.

A tal proposito, questa difficoltà nel ricercare accessi più agevoli dipenderebbe anche dai valori utilizzati per calibrare il modello di costo, troppo bassi forse quelli assegnati dagli scriventi alle pendenze massime del modello (Fig. 3). L'affrontare direttamente la falesia, a nostro avviso, è indice di difficoltà di accesso lungo buona parte del bordo della giara, perché il GIS preferisce operare in forma diretta e lineare piuttosto che andare alla ricerca di un altro punto di accesso vicino, che sarebbe comunque di difficile raggiungimento, rendendo l'operazione più dispendiosa in termini di spesa energetica.

L'impressione generale che scaturisce da questa applicazione sul campo è che le LCPA non possano ricondursi, ovviamente, a manufatti stradali reali – che non è stato, ed a nostro avviso non sarà, possibile individuare sul campo, almeno per quanto riguarda la Sardegna – ma che invece siano utili a delineare quantomeno le tendenze generali relative al movimento in queste regioni interne dell'isola. Questo aspetto risulterebbe interessante anche grazie ad alcuni nuovi rinvenimenti di strutture e di materiali in dispersione lungo i tracciati indagati. Tale esito ci risulta ben più credibile ed avvalora, secondo chi scrive, seppur ridimensionandola in termini di precisione, la tipologia d'analisi che ne è risultata. Sarà importante poi proseguire le campagne di ricognizione sul campo in quanto sempre foriere di nuovi dati e spunti per la ricerca archeologica territoriale.

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ABSTRACT

For about ten years this research team has been experimenting with techniques of spatial and visual perceptual analysis using GIS on the Nuragic landscapes (Middle and Late Bronze Age) of different areas of Southern Sardinia. Over time, various field campaigns have been developed on the monumental complexes built by the Nuragic communities. Towers, fortresses, villages, tombs of giants and sacred wells suggest a marked attention to the display of a message of power, strength and monumentality by the human group studied. An aspect often emphasized by these researches is the relationship of monuments with mobility and with the routes and strategic points of the territory, often verified through matches of different Least Coast Path Analyses (LCPA) that cross the territory by connecting different patterns of points. However, the real efficiency of the paths predicted by the GIS has never been directly tested on the ground. The paper presents the result of field analyses conducted by our group of archaeologists on the paths resulting from the GIS analysis in the Marmilla territories: travel times, energy expenditure and the real possibility of a path to actually cross a given territory are provided. Working with the LCPAs is still to be explored, however it remains a valid tool for territorial research, if an analysis unrelated to preconceptions and with a holistic evidence framework is carried out.

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# ROMAN LAND USE AND ITS IMPACT ON THE PANNONIAN LANDSCAPE

## 1. Introduction

Contrary to the Mediterranean, indirect, unbuilt traces of Roman occupation and settlement in the Northern provinces are difficult to detect. Not only the detection of former villa buildings or settlement traces, but also the identification of traces of Roman land use can be problematic. The Northern provinces, such as Pannonia, came under Roman rule in the early imperial period, when they began to be pacified. In these areas the military presence can be traced from the 1st century AD. The process began with the building of military camps and then, as the camps were abandoned, colonies and other civilian settlements have arisen on their place. This is currently the main schematic picture of the early development of Pannonia. The first Roman colony of Pannonia was Savaria (Fig. 1), the birthplace of St. Martin of Tours. Despite what has been described above, no earlier legionary camp has yet been identified in Savaria. But around the settlement, which was founded around present-day Szombathely (Hungary) in ca. AD 50, during the reign of Roman emperor Claudius, the land was probably given to the veterans of the *XV legio Apollinaris*. The veterans who were settled were allocated parcels of land. So the surrounding area was determined by the regular system of land occupation established by the *centuriatio*. There are now solid archaeological arguments in favour of the Pannonian design of this parcel system.

## 2. Research history of the *centuriatio* in Savaria

During the 1960s and 1970s, when the *centuriatio* research started in Western and Southern Europe (Caillemer, Chevallier 1954; Bradford 1957), the use of aerial photographs was highly restricted and forbidden in Hungary. Even topographic maps were secret and of limited use. In the absence of aerial photographs, A. Mócsy (1965) attempted to reconstruct the traces of land division from the early period of the Roman empire in Pannonia and present-day Hungary based on topographic maps. In doing so, he has mainly investigated and documented the existing perpendicular network of roads, which can be identified on Gauss-Krueger topographic map sections at a scale of 1:50.000. Mócsy proposed a *centuria* system with a 67-68° (+n×90°) bearing angle (Gauss-Krueger projection) and a size of 16×25 *actus* (568×887.5 m). Since his publication, apart from E. Tóth's territorial reconstruction (Tóth 1977) and the article by Lajos Négyesi on the network of villa buildings, there has been no substantial contribution to the interpretation of the *centuriatio*

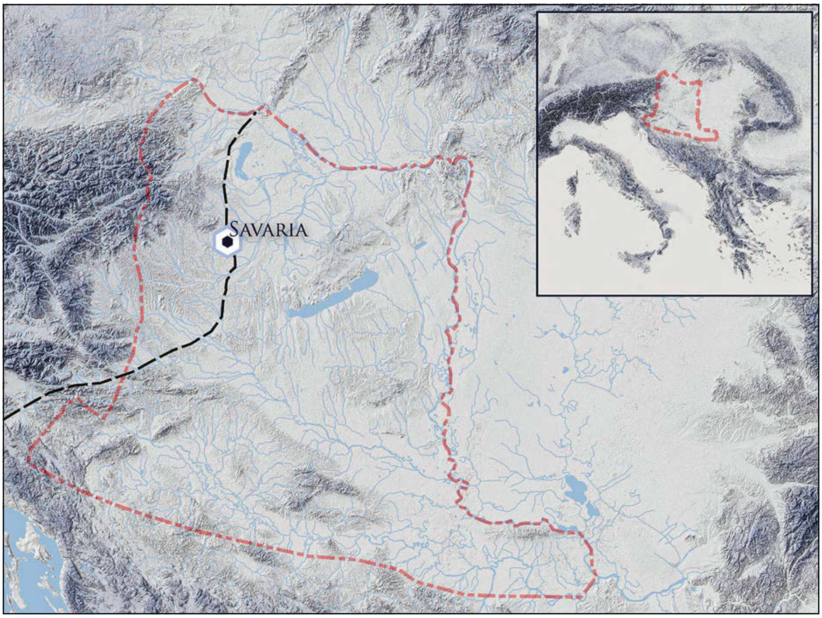


Fig. 1 – Pannonia and Savaria.

surrounding Savaria. However, A. Mócsy (1990) has already drawn attention to the fact that research in this direction is essential, both around Savaria and in the province. However this research had been remained practically abandoned for four decades, until a fortunate coincidence, in one of the pre-excavations of a road construction project in the late 1990s, a Roman dirt road crossing was discovered. Geospatial analysis showed that not only the roads at the cross-roads were parallel or perpendicular to the 25 km of arrow-straight Roman road published in the 1970s (Tóth 1977), but that they were regularly spaced at 1 Roman mile from it (Bödőcs 2008, 2013). By building a preliminary *centuriatio* model based on these values, we began to document various traces in the aerial photographs that corresponded to the model, and re-evaluated previous excavation data by using the model.

## 3. *Centuria* grid sizes

Based on the position of the archaeological sites, we searched for the best model to fit each known coordinate in order to reconstruct the most appropriate orientation and *centuria* dimensions. Since both the Hungarian topographic projection and the Roman division of land employ rectangular coordinate systems, the modern coordinate data were compared with the *centuria* values in a similar way to the Helmert transformation. Based on the differences of the x-y coordinate pairs and α degree rotation the relative *centuria* "coordinates"of the right-angled system were calculated using the following formula (Peterson 1993):

$$((X1\text{-}X2)\times\cos\alpha)\text{-}(Y1\text{-}Y2)\times\sin\alpha) \text{ and } ((X1\text{-}X2)\times\sin\alpha)\text{-}(Y1\text{-}Y2)\times\cos\alpha)$$

In fact, this can be considered as a relative Roman *centuriatio*-coordinate system. By using the relative coordinates of the sites, or the distance in Roman foot (*pedes*) and *actus*, it was also possible to calculate the possible side length – *modulus* – of a *centuria* unit.

According to ancient descriptions, the ideal *centuria* side-length was 2400 *pedes* (20 *actus*) and had a regular square shape, although ancient authors described other designs. By continuously varying the value of the angle α in the formula described above, it was possible to obtain a value which resulted in a rectangular grid with an orientation which, for all the known study points, showed the smallest deviation from the ideal (0) value. Based on these results, a regular square shaped *centuria* of approximately 707.5×707.5 m side length could be determined. The average value of the orientation angle α was 81.7°(+ n×90°) measured in the Hungarian projection (this is about 80° (+ n×90°) for the WGS84 projection). Thus, compared to the 16×25 *actus* grid proposed in the previous reconstruction, we were able to define *centuria* units with a base area of 20×20 *actus*, which was also considered as ideal by the authors of the *Corpus Agrimensorum*, with an orientation of 80° (+ n×90°) instead of the previously proposed orientation of 67-68°(+ n×90°).

## 4. Control data

Hundreds of military images, taken between the 1950s and 1980s, were reviewed and other available satellite images (e.g. Google Earth) were analysed using the newly defined parameters. New excavation data was inserted into the system as control data. Furthermore aerial recognition was carried out to locate possible road crossings based on our model. In many cases, we were able to document or recognise the significance of phenomena that we would have missed without the model. There was usually a very small difference (<10-15 m) between the theoretical coordinates and the documented traces, which shows the astonishing accuracy of ancient surveyors.

During this process we could found the westward branch (Fig. 2, left) of the Roman road that was mapped E of the town in the 1970s (Tóth 1977). They were practically connected along a line (Bödőcs 2013). This road is most probably the main axis, the *decumanus maximus*, of the *centuriatio*. We also tried to confirm the model by geophysical research (Fig. 2). The results

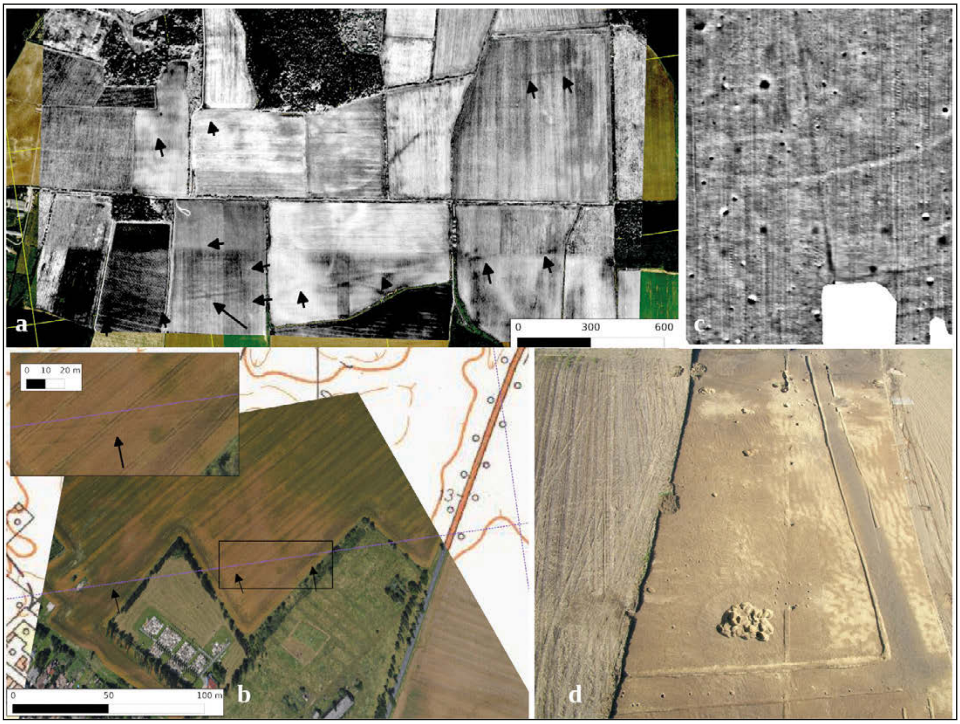


Fig. 2 – The visible traces (left to right) of the *centuriatio* of Savaria on a) archive photos; b) recent oblique photo; c) on geophysical suryey, and d) the excavated surface of Roman *centuriatio*'s road crossing.

showed that the *centuriatio* model is correct and working. We collected data continuously since then.

Surprisingly, not just a single section of formerly roads, but coherent (ca. 10-12 neighbouring) *centuria*-divisions could be documented in the late spring and late autumn images (e.g. Google Earth) since years 2018-2022. Based on this, we have launched new research that now aims to conduct a geophysical survey of the entire surface of the known *centuriae*, in order to get an image of possible parcels within a single *centuria*, thus detecting veteran estates. The results of this study are expected by 2023-2024.

## 5. The relationship between *centuriatio* and landscape

One of the most striking things we observed was how precisely Roman engineers could work. The observed phenomena hardly deviated from the theoretical, computer-designed network, which shows their geodetic skill. At the same time, this raised several questions which indirectly led to a kind

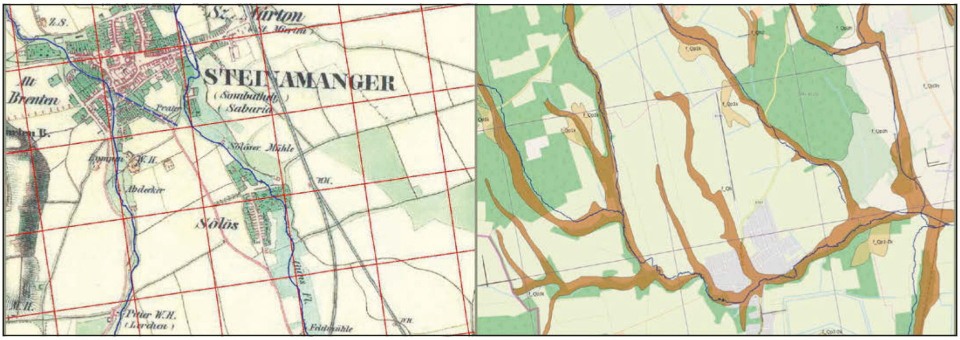


Fig. 3 – The Habsburg military survey showing the 19th watercourses S from the Roman colony with the *centuriatio* grid (left); the sediment map of the Ják-Sorok region shows the alluvial soil corresponding to the *centuriatio* grid (right).

of environmental reconstruction questions and answers. The research has long adopted the words of ancient geographers describing Pannonia as a topos-like contiguous forested area. The image of the *glandifera Pannonia* (acorn-bearing) suggested that there were extensive woodlands here, where the new veterans arrived at and, like the medieval hospices, cleared forests to acquire land. Even charcoal layers found in late Iron Age strata during soil drilling were attributed to this. This was clearly not the case, given the extensive geodetic work. The available *centuriatio* traces suggest the formation of a large land division grid, which was already in use at the time when the first *veterani* arrived after the foundation of the town. If they had been arrived to contiguous woodlands, this could hardly have been done in a short time. This is not an insignificant point since a few decades earlier there had been a rebellion over the lands of the resettled veterans. Whoever staked out a straight line in a forest have experienced that it is almost impossible to stake out a large area quickly in this way. For this reason, it can be assumed that the Romans were greeted by a landscape similar we have today.

Another interesting point is that a comparison of the *centuriatio* grid and the geographical (mainly hydrological) environment reveals the extent to which there is a correspondence between the Roman division and the hydrography (Fig. 3). The hydrographic data from maps of Habsburg military surveys show the situation before the great water regulations in Hungary in the second half of the 19th century (Kovács 2010) and a lot of similarities with the *centuriatio*. Some of the watercourses, instead of flowing downstream in the area, take a sharp, sometimes 90° bend and flow in a different direction according to the orientation of the *ceturiatio*. Although of course we cannot exclude the possibility of coincidences, it is striking that these phenomena often run unusually, and also unjustifiably, like based on the Roman pattern.

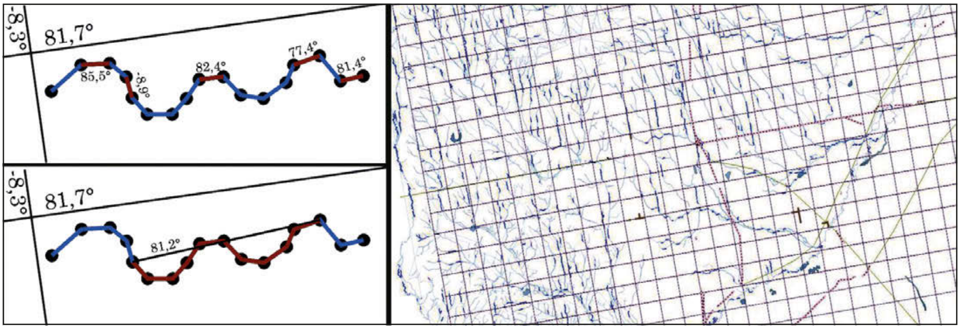


Fig. 4 – The methods and the results of the hydrological vector layer analysis.

The *centuriatio* model has not only opened new possibilities to hypothesize and locate former roads or sites along roads (such as burials), but also to investigate Roman attempts to transform the natural environment. The large-scale parcelling out of the land may have involved the construction of irrigation and drainage channels (Chouquer, Favory 1991, 103). The borders of the *centuriae* were often formed by artificial elements (roads, ditches, canals, possibly tree-lined streets), whose directions coincided with those of the rectangular system. The reason for this is that the boundaries of the estates may have been formed not only by field roads but also by common drainage or irrigation channels. This could not only involve the digging of smaller canals, but also the diversion of prehistoric (ancient) watercourses into new channels, altering the natural environment. Traces of this can be found in some sections of watercourses, which have been analysed using GIS tools to find a correspondence between the course of the water system and the direction of the land allotment system (*centuriatio*).

These channels have now become the natural beds of watercourses. The artificial transformation of watercourses is already attested. In fact in Szombathely, S of the former *colonia*, an earlier branch of the Perint stream, not documented in the maps of 19$^{th}$ and 20$^{th}$ centuries (Fig. 3, dotted line), has already been identified during archaeological excavations (Mladoniczki, Sosztarits 2009; Bödőcs, Kovács, Anderkó 2014). This is a branch that corresponds more to a natural flow direction, while the still active bed of the Perint stream in this section turns sharply southwards and follows the orientation of the *centuriatio* for almost 1.5 km. The established property boundaries (roads, canals) may have survived somehow until the Middle Ages, and sometimes until the modern era.

Although the GIS analyses have identified several areas where the current picture of the hydrological environment differs slightly from the "expected"

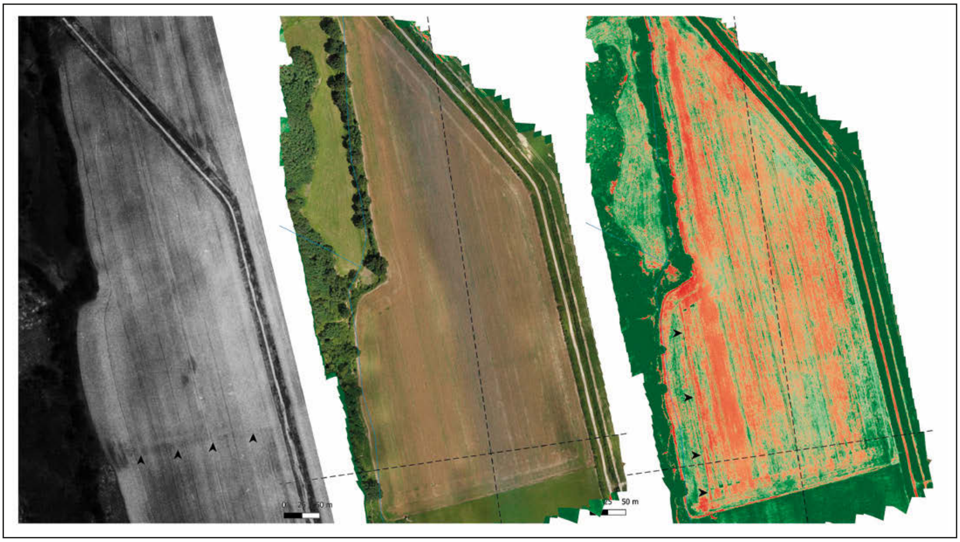

Fig. 5 – Details of the Ják-Sorok region (left). Aerial photo from 1993 showing the *centuria* border, and the result of the UAV surveys in visible spectral range (middle) and NDVI composite (right).

flow direction based on topographic conditions, the results are not yet available. In this modelling exercise, a preliminary study produced from a current digital surface model (SRTM) was used to delineate zones defined by comparing the recent hydrographic environment with the modelled runoff. In these zones, "unexpected" changes in flow direction, not fully explained by topographic conditions, were observed in many cases (Kovács 2013). Another geospatial analysis method was used to investigate the digitized trajectories of current river flows.

Based on the assumption that, although an artificial canal was once constructed with the same orientation as the *centuriatio*, the former artificial beds may have gone wild after regular maintenance ceased, becoming active watercourses with natural meanders along the course of the riverbed. Therefore, map analysis was used to compare the different sections of each watercourse. The digitized hydrographic layer was divided into edges and vertices and so one edge's orientation by one, or "in blocks", i.e., 10 sections' average orientation was analysed together at the same time (Fig. 4, left). Thus, a distribution map (Fig. 4, right) was produced for the hydrography of the area, on which the watercourse sections that could be correlated with the *centuriatio* orientation were marked (Bödőcs, Kovács, Anderkó 2014).

It should be noted that, unlike man-made artificial features (e.g. roads), in the case of watercourses the course is not expected to be perfectly straight, since the energy of the watercourse has been able to shape its bed since Roman times, i.e., it only maintains the main course of the river. In the case of a stream with a higher water flow, the flow direction in the area is usually broken, briefly taking the direction marked by the grid and then returning to its previous natural direction.

When mentioning the modification of the water system around Savaria, we should also note the recently excavated riverbed (Mladoniczki, Sosztarics 2009, fig. 1), which existed in the Roman times and has since then been filled in, and which may have connected the waters of the present-day Perint and Gyöngyös creeks. If we assume that this section could be an original riverbed, we must also consider the section of the Perint creek S of the town to be artificial (Fig. 3, left). The stream, after flowing NW-SE direction, turns sharply and flows S for 2 *centuriae*, whereas the natural flow would be in a SE direction. A branch is still marked here on a map from the 18th century, and we even know from early modern descriptions that it was fenced by a palisade (Horváth 1993, 15-16). Excavation has indeed revealed traces of this palisade and of a former water basin. However, the branch that still exists today runs southwards for about 1 Roman mile, according to the *centuria* borders.

In this region, we have noticed several places where the streams run in a surprisingly straight line (Fig. 3, right) following the orientation of the *centuriatio*. So, we started to investigate sections that change direction sharply at confluence. We are currently trying to detect an earlier buried streambed by using remote sensing. From 2022 onwards, the research has continued with multispectral UAV imagery in addition to the analysis of available imagery. Multispectral UAVs were chosen because the infrared resolution of the available satellite data is not fine enough to detect smaller channels. Although the resolution of multispectral UAV cameras is around 2 mP (DJI Phantom 4 multispectral with RTK module), a field resolution of centimetres can be achieved by choosing the appropriate flight altitude.

Although the surveys have only recently begun, some of the recordings have already shown interesting results (Fig. 5). In the pictures taken in the NIR and RedEdge infrared range, an interesting channel(?)-like phenomenon was documented along the Ják-Sorok stream, whose sections fit well with the orientation of the *centuriatio*, which constitutes a straight continuation after the right-angled break in the stream bed. By verifying these and similar phenomena with geophysical research, we hope to obtain a more detailed picture to support the theory of the landscape transformation effect of *centuriatio*.

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ABSTRACT

The Roman colony of Savaria was the first founded town in Pannonia (*Colonia Claudia Savaria*). Some inscriptions attest the so-called *deductio*, the settlement of veterans. After the first reconstruction of the *centuriatio* of Savaria no substantial archaeological attempt has been made in the last 40 years to verify the theory. In the last decade, research into the existence of the Savarian *centuriatio* has been pursued by using GIS methods, thanks to which we have managed to build a predictive model-network for the *centuriatio*, which is completely different from the previous reconstructions. The model has been continuously refined and validated by archaeological fieldwork and geophysical survey. The new reconstruction has led to new possibilities for interpreting the sites excavated in recent decades and the previously known Roman roads and aqueducts. Another interesting relationship between the watercourses running through the former *colonia* and the Roman *centuriatio* was also detected: the impact of Roman agriculture on the landscape transformation that has survived to the present day. Our pilot project, launched this year, plans to verify these effects using multispectral UAV surveys and geophysical measurements to show whether there were former streams along the presumed Roman channels that could provide evidence to support this hypothesis.

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# THE ROMAN *LIMES* IN *GERMANIA INFERIOR*: A GIS APPLICATION FOR THE RECONSTRUCTION OF LANDSCAPE

## 1. The Roman *limes* in the province of *Germania Inferior*

At the height of its expansion, during the first two decades of the 2nd century AD, the Roman Empire extended from the Iberian Peninsula to Arabia, and from North Africa to Britain (Grassi 2011). The Roman expansion was a long process that has in the defeat of Carthage, in the second Punic war, at the end of the 3rd century BC, a crucial turning point for Rome in acquiring a predominant role in the Mediterranean basin. The maximum expansion of the Roman sphere of influence was reached during the reign of the emperor Trajan, with the conquest of Dacia and Arabia provinces. It is this long process that resulted in the formation of the Roman *limes*, a frontier long more than ten thousand kilometers. The *limes* should not be considered as a permanent defensive barrier between the Roman and the barbaric world, or as the result of a deliberate political choice, rather it must be considered and studied as the result of fossilization of a contact line between two or more conflicting forces (Maggi 2011).

The *limes* system is focused both on the presence of natural physical barriers, such as the Rhine and Danube rivers in Europe and the Sahara Desert in North Africa, either on the presence of fortified sections such as the Hadrian's wall or the Germanic-Rhaetian *limes* (Barbero 2007). In the case of the province of the *Germania Inferior* (corresponding to today's Netherlands and part of North-West Germany), annexed between the half of the 1st century BC and the first decades of the 1st century AD, the Roman *limes* come to coincide with the course of the river Rhine (Fig. 1), a natural barrier capable of marking the division between the Roman domains and the Celtic-Germanic tribes not subjects to Rome (Visser 2015).

The Rhine area has undergone considerable environmental and anthropogenic change over the past 2000 years, leading to substantial modification in river courses, coastline, vegetation and land use. The Rhine diverted its main branch southward during the early Middle Ages, and the present shoreline dates from the late medieval period, changes that resulted in a considerable mutation of the geomorphological setting from the Roman period. A palaeogeographical map of the NW part of the *limes* zone was already assembled on the basis of an extensive database of geological bore holes collected by the University of Utrecht, and of detailed LiDAR-based elevation data (Van Dinter 2013; Verhagen, Jamie, Groenhuijzen 2019).

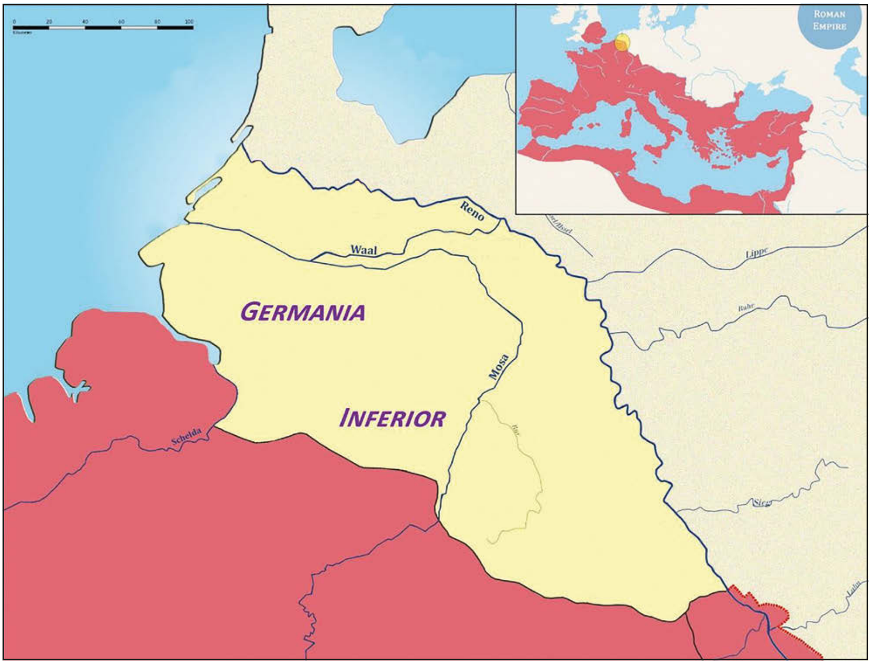


Fig. 1 – The Roman province of the *Germania Inferior*.

The archaeological research carried out in the area of the lower Rhine allowed the identification of the remains of the fortification system built by the Romans for the frontier control. In the area of Rhine-Meuse delta, by mid-1st century AD, a series of small auxiliary forts was built in the western part of this delta from the present-day city of Utrecht down to the North Sea, over a distance of about 60 km (Bosman, De Weerd 2004; Polak, Kloosterman, Niemeijer 2004; Polak 2009; Van Dinter 2013; Verhagen, Jamie, Groenhuijzen 2019). The fortifications were constructed on the left bank of the Lower Rhine. In 1970 in the city of Leiden, in the Roomburg district, thanks to the geo-radar survey, was discovered a fort with approx. size of 82×100 m. This is probably to be referred to a contingent of auxiliaries, probably on horseback, as the discovery in the area of a knight's parade mask seems to suggest. Also, thanks to the investigations conducted in the final years of the 20th century, the discovery of laterite stamps can be attributed to the contingents settled in the *castrum*. They are the *Cohors I Lucensium Hispanorum*, the *Cohors XV voluntarium civium Romanorum pia fidelis*, and the *Numerus exploratorum Batavorum* (Haalebos, Willems 1999).

In the center of Utrecht, below the square of St. Martin's Cathedral, the archaeological investigations have revealed the presence of two distinct phases of a second auxiliary encampment.

An early wooden structure, dated on the basis of materials found between AD 50 and AD 150, appears to have been overlaid by an encampment with stone structures measuring about 160×124 m. Such structure remained in use until AD 260, when the encampment, similar to other outposts on the Rhine was abandoned by Roman soldiers (Lendering, Bosman 2012). Another encampment for auxiliary troops was identified in the first half of 20th century near Vechten, where parts of the fortification perimeter and the soldiers' accommodation structures have emerged (Zandstra, Polak 2012; Polak 2014).

In the area of Nijmegen two distinct phases of a military settlement have been attested. The first is before the Batavian rebellion in AD 70 and consists of a large camp and a second small fort for an auxiliary contingent. Both were probably destroyed during the revolt, and in a later phase only one main legionary camp was erected (Willems Bradley 1992; Lendering, Bosman 2012). The numismatic and ceramics finds related to the first phase of occupation revealed the presence in the area of two main legions, the *I Germanica* and the *XIII Gemina*. Such evidence also made it possible to date the first phase of occupation of the site, between BC 19 and AD 12, probably related to the operations conducted by Drusus in the area in preparation for future Germanic campaigns (Willems 1990).

In the province of the *Germania Inferior* a second main legionary camp has been identified near Xanten, the site where in the AD 100 was established the Colonia *Ulpia Traiana*, in the place of an old settlement (Heimberg 1999). The earliest phases of the *castrum*, used by Drusus during his expeditions to *Germania Magna*, are still unknown to this day, as archaeological investigations in the past decades have focused mainly on Neronian-era structures. The first legion attested in the fort, known as *Vetera*, is the *legio XVIII* belonging to Varus' army, whose presence is documented by the cenotaph of centurion M. Caelius (Maggi 2011, 107). After the defeat of Teutoburg and the subsequent destruction of the three legions in the province, the consul Lucius Asprenate occupied the site to prevent the Germans from invading across the Rhine. In this phase the *castrum* was probably rebuilt by the future emperor Tiberius and the wooden fort was large enough to accommodate two legions, the *V Alaudae* and the *XXI Rapax*. Both later took part in Germanicus' campaigns between AD 14 and 16 (Lendering, Bosman 2012).

Around AD 30 the fort was demolished and rebuilt again. The reconstruction is traced back to AD 43, when the *legio XXI Rapax* was replaced by the *legio XV Primigenia*. The structures of the encampment were equipped

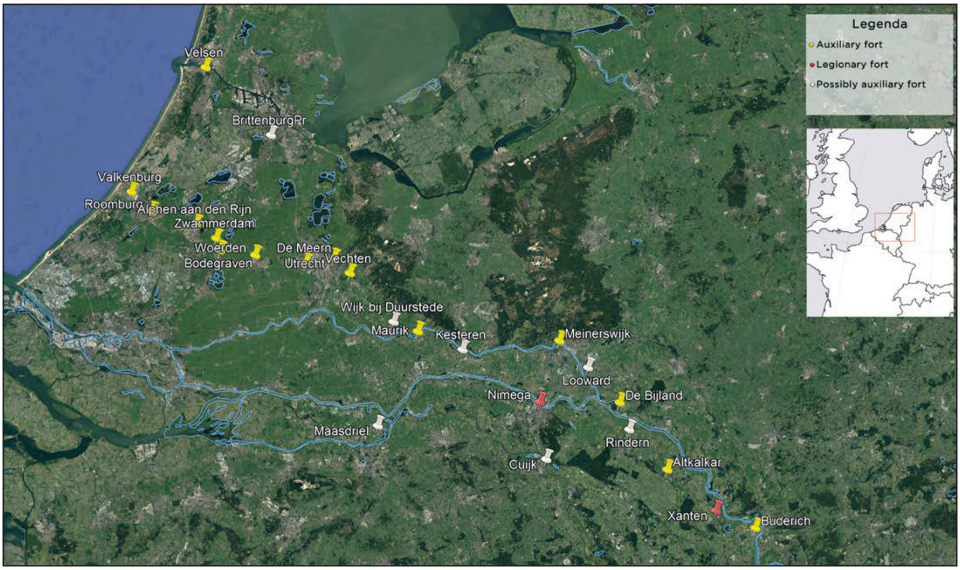


Fig. 2 – Location of the Roman forts across the Rhine *limes* system.

this time with local stone and brick foundations. A final rebuilding of the *castrum* was instead traced back to the sixth decade of the 1st century AD. This structure corresponds to the one razed to the ground by the Batavians during their revolt. The *castrum* was never rebuilt again by the Romans, just as the two legions that occupied it were never reconstituted. After quelling the Batavian uprising a new legionary base was built by *legio XXII Primigenia* in an area located in the immediate vicinity of the river, just over a kilometer from the previous one. The fort known as *Vetera II*, however, has never been archaeologically investigated, as it is now completely submerged by the modern course of the river Rhine. The site, extending roughly between 20 and 25 hectares was identified in 1960, by a group of underwater archaeologists, led by W. Piepers, at a depth of more than 10 meters (Lendering, Bosman 2012).

Thanks to the data collected in the course of the archaeological research conducted along the *limes* it has been possible to reconstruct how the system of Roman fortifications developed in the Rhine area. The Rhine *limes* was centered on a system of roads, initially used for the movement of troops, close to the river on which the various encampments were located, in a position to facilitate communication between them. Among these forts, numerous watchtowers had the role of patrolling the banks of the river and alerting the nearest encampment if the enemy approached. The camps could vary in size

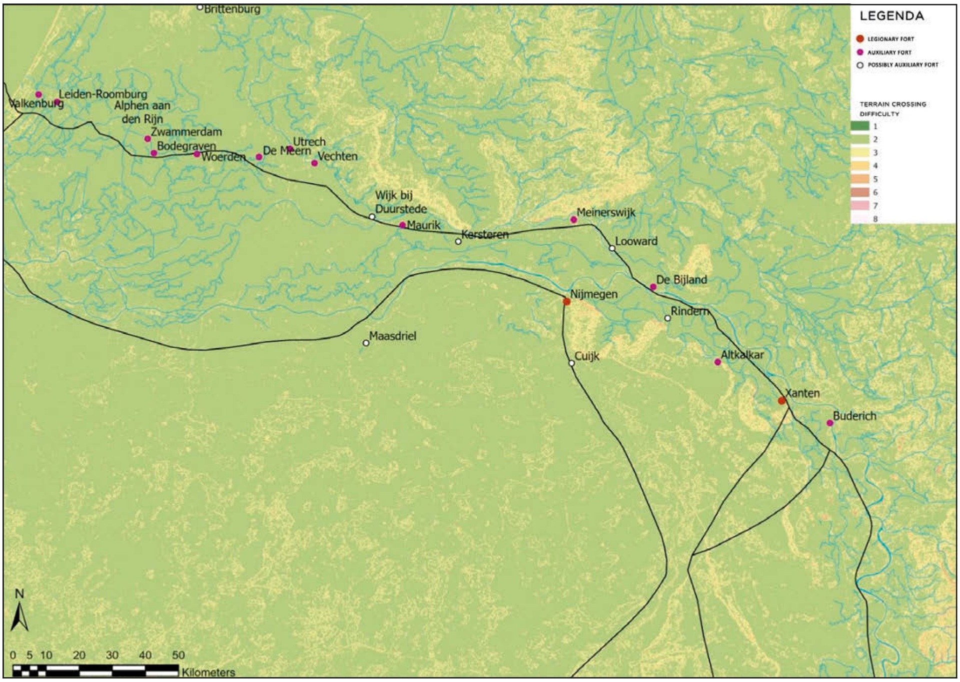


Fig. 3 – The Digital Terrain Model of the Rhine *limes* area.

according to the number of troops deployed inside, however they maintained a standardized structure in which we recognize the army headquarters, the warehouses and barracks.

The size of the forts varied, depending on whether the camp was intended to host a legion, the main unit of the Roman army, or auxiliary contingents, such as light troops, cavalry or skirmishers with supporting tasks. At present we count 17 military camps (Fig. 2). These including 2 for legions and 15 for auxiliary contingents. It is also assumed the presence of at least 6 other auxiliary camps in the area of lower Rhine.

V.R.

## 2. Spatial analysis applied at the Roman *limes* in *Germania Inferior*

In order to verify the position of these hypothetical forts, a visibility analysis and path distance analysis was carried out based on the location of certain sites and taking into account the ancient road routes and the geomorphology of the soil. For this purpose, has been created a raster cost surface (Fig. 3). A model of the terrain that expresses the difficulty of crossing, useful for spatial analysis of travel (Llobera 2000). The model is the sum of various factors like altimetry, slope, presence of streams, which hinders the crossing, and roads which instead facilitates it (De Silva, Pizziolo 2001; Citter, Arnoldus-Huyzendveld 2011). The visibility analysis allows to calculate the horizon visible by the human eye, taking into consideration the position of the observer, its height and the morphology of the landscape. This approach offers the possibility of simulating and reconstructing part of the complex relationship between the settlement systems and the morphology and landscape characteristics (Wheatley 1995). To calculate the area of visibility of each settlement it is necessary to define the parameters of the hypothetical observers. The height of the observer was estimated at 1.65 m, with a field of view of 18-20 km (Wheatley, Gillings 2002; Pecere 2006).

Thus, defined the observer, it is possible to perform the function of calculating visibility, which compares the characteristics of the observation point with the height of the surrounding areas, identifying on the basis of the dimensions what is visible. Intervisibility analyses have also been carried out between the various sites, to determine whether two observers were mutually visible and therefore in direct communication. On this basis, it was performed both a path distance analysis, recalibrated to represent the route taken in about 8 hours of a soldier's march, and the visibility analysis to determine what was visible from the various settlements, assuming an observer on a tower of approx. 5 m. The application of spatial analysis makes it possible to reproduce predictive models, assuming the presence of archaeological contexts through the study of known data, and to investigate the ancient landscape. Specifically, during this investigation, it was decided to apply visibility and distance analyses. Firstly, it was possible to demonstrate how the Roman forts located near the *limes* in *Germania Inferior* responded to specific requirements: 1) their position allowed an extensive visual control of the surrounding area, especially the main roads; 2) the distribution of the forts also seems to have been determined by the capacity and timing of movement.

As we have said, visibility analyses allow to determine the horizon visible to the human eye (Wheatley 1995). Their use in research has long been established, especially in relation to studies of cognitive archaeology. The visibility of a place is, in fact, one of the tools for creating a group's memory (Bradley 2002) and a powerful communication tool (Semeraro 2009).

In relation to this study, it is also important to underline how Polybius already mentioned the use of light signals in times of war, testifying to the importance and diffusion of these forms of distance communication (Pol., 10, 45-48).

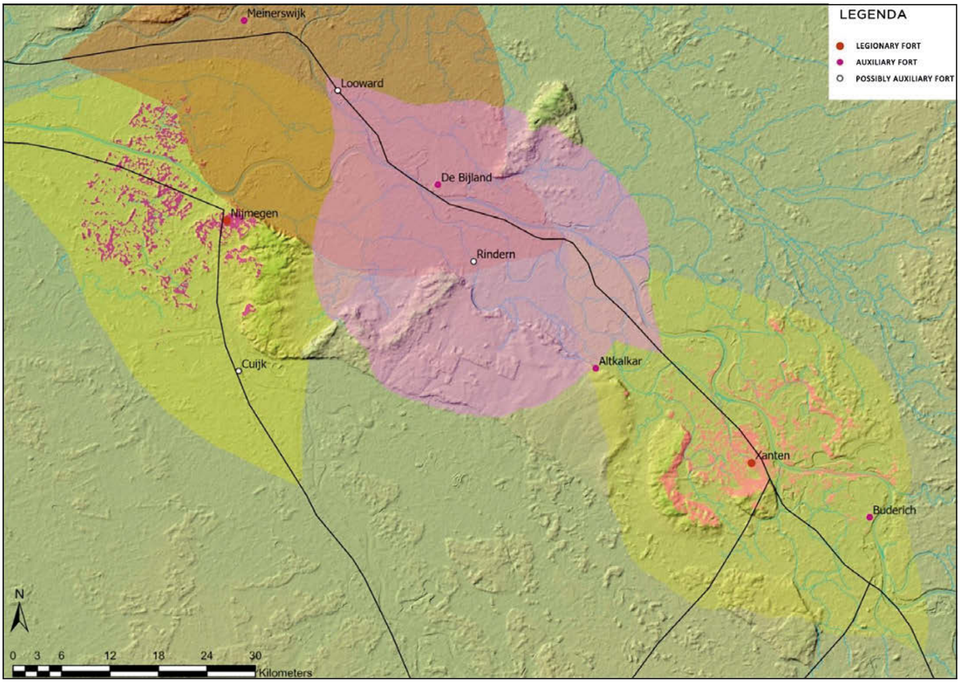


Fig. 4 – The Path Distance Analysis of the area between Nijmegen and Xanten.

For the analyses performed, an observer height of 1.65 m was estimated, to which 5 m were added to assume the presence of towers, while the visibility range was calculated to be 18-20 km (Wheatley, Gillings 2002; Pecere 2006). The ground elevation, on the other hand, is obtained from a DEM, i.e. a raster file in which each pixel represents the altimetric value of the ground with respect to sea level. To process the DEM of the area under examination, we chose to use the satellite images made available by the European Space Agency-ESA (https://www.esa.int/), processing the model using the specific software SNAP (https://step.esa.int/main/download/snap-download/). The SAR signal is determined by two main characteristics: "amplitude", which indicates the strength of the radar signal response, and "phase", a single wavelength due to the distance between the satellite and its target on the earth's surface, thanks to which a DEM can be derived (Bhattacharya, Arora, Sharma 2012).

The InSAR (Interferometric Synthetic Aperture Radar) technique allows to extrapolate a digital terrain model from these data. For the processing, the methodology recommended by the agency itself was followed (Braun

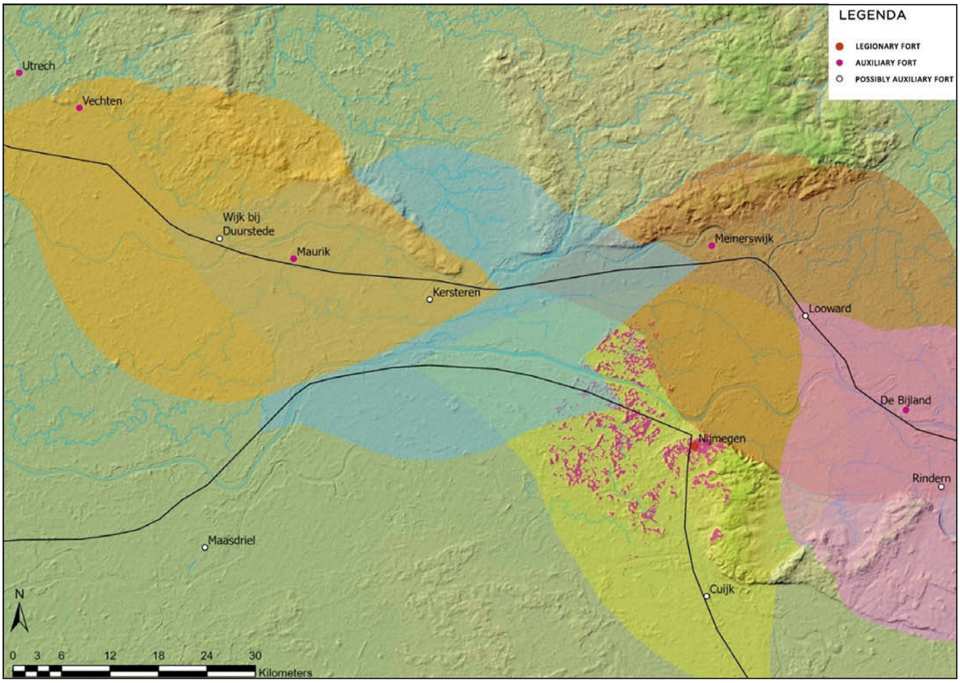


Fig. 5 – The Path Distance Analysis of the area between Wijk and Kersteren.

2021). On this basis, the position of each observer in the surrounding terrain is compared within a radius of approx. 20 km, highlighting the areas visible from it. In addition, intervisibility analysis has been carried out, in which it is shown whether two observers are mutually visible, thus reconstructing a communication network between the centers. The realization of the distance analyses, on the other hand, required the elaboration of a cost raster, in which each pixel corresponded to the crossing difficulty. For these reasons, different parameters were examined, to which different percentage weights were attributed. Specifically, data relating to the nature of the terrain, such as altimetry, slope or presence of watercourses, and data relating to human impact, such as the presence of roads or built elements, were processed (Tab. 1).

| VARIABLES | OVERALL WEIGHT (in percent) |
|---|---|
| Slope | 40 |
| Altimetry | 20 |
| Environmental factors | 20 |
| Anthropic factors | 20 |

Tab. 1

The factors under consideration were calculated on a scale of 1 to 8, with 1 being the lowest difficulty value. Slope was one of the factors with the greatest percentage weight, since up to 6° it is possible to take optimal routes in both directions (Llobera 2000), and up to 10° water stagnation is minimal (De Silva, Pizziolo 2001; Citter, Arnoldus-Huyzendveld 2011); a slope greater than 14°, on the other hand, significantly increases the cost of travel and does not offer good potential for human settlement (Van Luesen 1993; Minetti 1995).

The model obtained expresses, on a scale of 1 to 8, the difficulty of crossing the terrain. The distance analyses performed can be divided into two groups: the hypothetical reconstruction of the shortest path between two points and the calculation of the energy consumption or time spent by an individual to move through space (Forte 2002, Wheatley, Gillings 2002).

In archaeological research, the latter are often employed as catchment analysis (Vita Finzi, Higgs 1970), based on the methodological assumption that a community minimizes effort for its main subsistence activities. Based on anthropological and ethnographic studies, some general parameters have been provided for nomadic or sedentary groups (Chisholm 1962). In this analysis they were used to calculate the area accessible from the various centers in ca. 8 hours of walk, average walking time of a legionnaire. For example, in the area of Xanten-Nijmegen, where we see the area visible and reachable by both forts. Buderich is both visible and reachable from Xanten, while Altkalkar is not visible (Fig. 4). So, if there was a visual communication system between the different forts, it is possible to hypothesize an intermediate camp not yet known.

In this case the two hypothetical centers of Looward and Ridern would represent perfect points of conjunction of the network of Romans forts. Also, in the area between Wijk and Kersteren (Fig. 5) the distance analysis seems to confirm the excellent position of the sites to accommodate a fort. In both cases the visibility analysis and path distance prove to be a useful tool to verify the hypotheses about the location of forts, belonging to the *limes* system, which, at present day, is only assumed. A research methodology that, if applied to the entire limited system, could provide interesting information for the future research about a cultural heritage recognized in 2021 in the Unesco World Heritage List.

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## ABSTRACT

The Roman Limes represents the border line of the Roman Empire at its greatest extent in the 2nd century AD. It stretched over 5,000 km from the Atlantic coast of northern Britain, through Europe to the Black Sea, and from there to the Red Sea and across North Africa to the Atlantic coast. The remains of the Limes today consist of vestiges of built walls, ditches, forts, fortresses, watchtowers and civilian settlements. The limes system is focused both on the presence of natural physical barriers, such as the Rhine and Danube rivers in Europe and the Sahara Desert in North Africa, either on the presence of fortified sections such as the Hadrian's wall or the Germanic-Rhaetian limes. The latter two are the best preserved and studied section.

However, the limes sections in which natural barriers were exploited to mark the boundary of the area under Roman control are less well known. Over the past two decades considerable progress has been made in the knowledge of limes areas such as the Rhine sector. In this area the river was exploited as a natural barrier, and control of the area was based on the presence of two larger legionary camps around which, along the southern course of the Rhine, small auxiliary camps gravitated. Only some of these encampments have been investigated and their position confirmed by archaeological excavations. The position of the other encampments is still speculated and awaiting verification. In this contribution, in order to verify the position of these hypothetical forts, through GIS systems a visibility analysis and path distance analysis were carried out based on the location of certain sites and taking into account the ancient road routes and the geomorphology of the soil.

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# MODELO PREDICTIVO DE APROVECHAMIENTOS VITIVINÍCOLAS. LA COLONIA ROMANA DE *HASTA REGIA*, *HISPANIA*

## 1. Introducción

En este artículo se presenta un método para predecir áreas de aprovechamiento vitivinícola en época romana, con el objetivo de poder ser reproducido en otros espacios. El método tiene dos puntos principales. Por un lado, recopilar y establecer los criterios geográficos y ambientales que se van a considerar para asignar a cada celda del ráster un potencial uso agropecuario. Por otro lado, utilizar un método de asociación de estos parámetros con yacimientos arqueológicos específicos, como puede ser una *villa*, haciendo un área de influencia de cada lugar. Esto nos permite calcular el porcentaje que ocupa un uso agropecuario. De esta forma podemos entender la relación de sitios arqueológicos con el paisaje y sus usos, así como modelizar dichas condiciones en otros espacios para predecir lugares que cumplan con criterios similares.

Historiográficamente se han desarrollado diversas investigaciones sobre como modelizar el paisaje antiguo mediante SIG (Goodchild 2007; Viitanen 2010), línea a la que hemos contribuido sobre como localizar zonas óptimas de viñedo en base a los agrónomos romanos (Trapero Fernández 2016). En este sentido, se están realizando modelos similares en otros espacios como en la provincia *Tarraconensis* (Stubert *et al.* 2020) y en Galia (Bernigaud, Bondeau, Guiot 2021), además de otros estudios económicos y comparativos (Martín Oliveras 2015; Van Limbergen, Marécchal, de Clercq 2020; Dodd 2022). El método empleado en este artículo permite modelar el paisaje antiguo, en base a unos criterios dados que se especificarán, así como asociarlos a lugares concretos, algo novedoso pues podemos entender la relación que tiene un determinado centro productor con su entorno.

Usamos un caso de estudio como ejemplo para el modelo, la colonia romana *Hasta Regia*, en el suroeste de la Península Ibérica (Martin-Arroyo Sánchez 2018), muy cerca de la ciudad de *Gades*, de donde era originario Columela, el cual refiere en su libro prácticas agrícolas de la zona (Carandini 1983; García Armendáriz 1995). Se trata de un territorio que ha tenido gran importancia por la viticultura desde la antigüedad (Carreras Monfort 2001; Trapero Fernández 2021a), pasando por época medieval (Martín Gutiérrez 2018) y actualmente por los vinos de Jerez-Sherry. El espacio se encuentra en la orilla o paleo ribera del río Guadalquivir, denominado por Avieno como *Lacus Ligustinus* (Lágostena Barrios 2006), un área de estudio que hemos delimitado al interior por la cuenca vertiente del río, ya que sabemos con certeza que es territorio de la misma. Partimos de una serie de

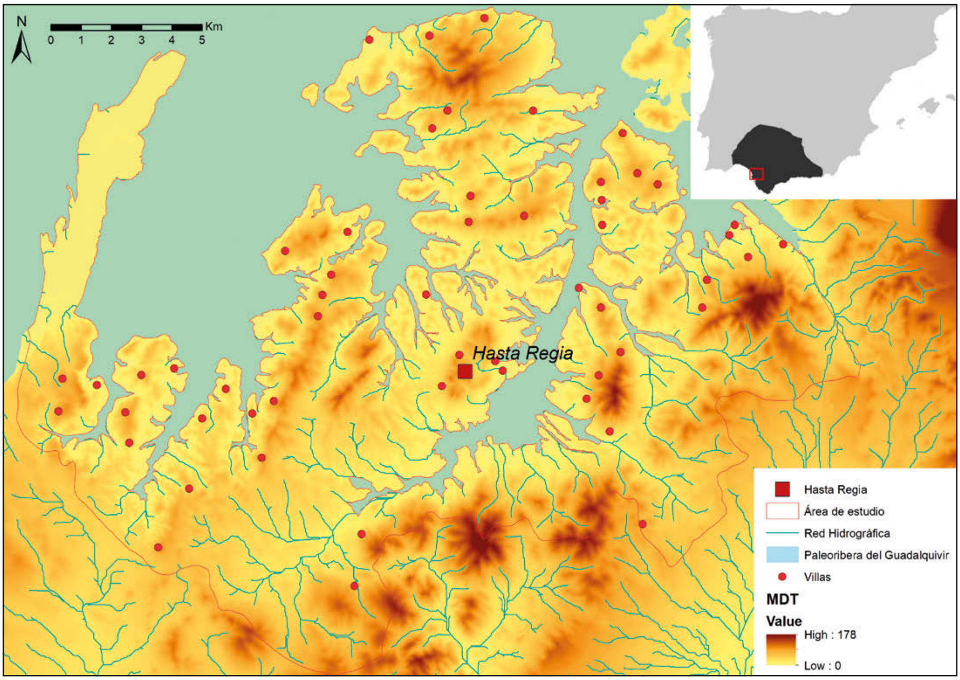


Fig. 1 – Localización del área de estudio con los principales elementos arqueológicos y paisajísticos.

prospecciones y estudios de materiales arqueológicos, en los que detectamos 53 *villa*, información complementada con un análisis SIG cuya metodología se amplia y desarrolla en un libro publicado (Trapero Fernández 2021a) y que es la base de este artículo (Fig. 1).

## 2. Metodología

### 2.1 *Criterios para generar un mapa de aprovechamientos agropecuarios*

Para generar el modelo predictivo, es necesario partir de una delimitación del territorio a estudiar, como en la Fig. 1, un MDT (modelo digital del terreno) y capas de información geográfica y ambiental, así como varias herramientas SIG, en nuestro caso mediante ArcGIS. Para generar el mapa de aprovechamientos agropecuarios, consideramos fundamentalmente cuatro criterios que se expresan en la Tabla 1. Cada uno se corresponde con una variable espacial que podemos medir en la actualidad y que tiene su reflejo en la mentalidad romana, gracias al conocimiento agronómico que nos ha sido legado.

– Primero, la pendiente (Surface/Slope) pues determina el uso preferente de la llanura para cultivos de cereal, colinas de viñedo o similares y, finalmente, otros aprovechamientos para la montaña (Var., *R.*, 3, 18, 2).

– El segundo es la orientación del terreno (Surface/Aspect), donde clasificamos cada inclinación preferente dependiendo de la insolación potencial, que será mejor en zonas que miren al Sur frente al Norte (Col., *Rust.*, 4, 22). Pero también hay que tener en cuenta los vientos, que en nuestra zona concreta son muy fuertes del Este y Sur (Col., *Rust.*, 3, 12, 6). Esto hace que tengamos una preferencia de cultivos óptimos como el viñedo hacia el Oeste y unas zonas al Norte que serán más umbrías reservadas para otros usos.

– Tercero, consideramos la edafología del terreno (Rediam 2022), según la clasificación FAO y sabiendo que hay una clara idoneidad de suelos dependiendo de su tipología, por ejemplo, los suelos de marisma, dunas o montañosos, con poco o nulo uso agrícola. Conocemos la preferencia de determinados tipos de suelos para viñedo específicos de la zona de estudio por referencias antiguas (Col., *Rust.*, 12, 21, 5-6), por lo que se puede dividir los tipos fundamentalmente en seis grupos. Primero, los suelos malos para la agricultura por marisma y arenas. Segundo, lugares de montaña. Tercero, formaciones calcáreas que requieren bonificación para su cultivo. Cuarto, suelos arcillosos que permiten determinados tipos de agricultura, al ser formación que se encharca y agrieta dependiendo del tiempo puede no ser bueno para raíces de árboles. Quinto, terrenos óptimos para varios cultivos, como los cerealísticos. Sexto, los más fértiles asociados a depresiones, aluviales y fluviales.

– Finalmente, consideramos la cercanía a arroyos y paleo costa (Proximity/Buffer) con un área de influencia de 50 m, que se reclasifica y convierte en ráster. Estar próximo a estos espacios implica que se pueden tener aprovechamientos maderos y cordelería, algo necesario y prioritario según los propios agrónomos (Var., *R.*, 1, 7, 9). Estos materiales generalmente requieren de condiciones de húmedas, ya sea agua salada o dulce, por lo que se reservaría su uso para estos menesteres (Cañizar Palacios 2016).

La asociación entre estas fuentes antiguas y geografía actual ya fue abordada anteriormente (Sáez Fernández 1987) y recientemente comprobada (Trapero Fernández 2021b), por lo que remitimos a estas publicaciones para más información.

El proceso metodológico requiere una reclasificación de los valores de la Tabla 1 (Reclass/Reclassify), de manera que cada criterio tenga un lugar en unidades, decenas, centenas y millares. Los distintos ráster se combinan mediante suma (Map algebra/Raster calculator), de forma que, por ejemplo, el valor 1111 se corresponda con una pendiente llana, orientación Oeste, suelos de marisma y cercanía a las zonas de aprovechamiento de riparia. Con este método podemos asociar fácilmente criterios agronómicos antiguos con los

| | | |
|---|---|---|
| **Pendientes** | | |
| Entre 0 grados y 5 grados | Superficie llana | 1 |
| Entre 5 y 10 grados | Colinas y dehesas | 2 |
| Más de 10 grados | Montes y montañas | 3 |
| **Orientaciones** | | |
| Oeste y noroeste | Protegido de los vientos | 10 |
| Sur y suroeste | Gran insolación, sin protección de vientos | 20 |
| Este y sureste | Sin protección de vientos | 30 |
| Norte y noreste | Protegido de vientos, baja insolación | 40 |
| Sin orientación | Superficie plana | 50 |
| **Suelos edafológicos** | | |
| Arenosoles álbicos, cambisoles húmicos y greysoles dístricos | Principalmente suelos de arenas, dunas. Poco substrato fértil | 100 |
| Solonchaks takírico y solonchaks gleicos | Marismas con alto contenido salino | 100 |
| Regosoles éutricos, xerosoles hápilicos y litosoles | Suelos con poco sustrato y rocosos | 200 |
| Regosoles calcáreos y cambisoles cálcicos con litosoles, fluvisoles calcáreos y redsinas | Suelos calcáreos que pueden ser bonificados | 300 |
| Regosoles éutricos, regosoles dístricos y aerosoles álbicos | Suelos mixtos de regosoles y arenosoles, óptimos para viñedos | 300 |
| Vertisoles pélicos y vertisoles crómicos | Suelos arcillosos, se encharcan en invierno y se agrietan en verano | 400 |
| Vertisoles pélicos, redsinas y regosoles calcáreos | Suelos arcillosos, se encharcan en invierno y se agrietan en verano | 400 |
| Cambisoles vérticos, regosoles calcáreos y vertisoles crómicos con cambisoles cálcicos | Permite gran rango de usos agrícolas | 500 |
| Vertisoles crómicos y cambisoles vérticos con cambisoles cálcicos, regosoles calcáreos y vertisoles pélicos | Suelos mixtos buenos para la agricultura | 500 |
| Cambisoles cálcicos, luvisoles cálcicos y luvisones crómicos con litosoles y fluvisoles calcáreos | Suelos muy buenos que permiten gran rango de usos agrícolas | 500 |
| Luvisoles cálcicos, luvisoles crómicos y luvisoles gleicos | Depósitos aluviales ricos en materia orgánica | 600 |
| Luvisoles crómicos, cambisoles cálcicos y litosoles | Depósitos aluviales | 600 |
| **Hidrografía** | | |
| Menos de 50 metros de un arroyo o paleo-costa | Aprovechamiento de riparia | 1000 |
| Más de 50 metros de un arroyo o paleo-costa | Aprovechamientos de no riparia | 2000 |

Tab. 1 – Elementos geográficos y ambientales con su valor reclasificado.

elementos actuales, visualizando cada combinación y volver a reclasificarla dependiendo de asignación de usos que demos, como puede ser agrícola, ganadero o forestal.

## 2.2 *Modelo de relación entre paisaje y yacimientos*

En un segundo nivel de análisis nos interesa relacionar los criterios antes generados con yacimientos arqueológicos concretos. Para época romana utilizamos la *villa* como modelo principal de ocupación y explotación rural. Sin embargo, generalmente tenemos información del sitio arqueológico en si mismo, no del área productiva que ocuparía, ¿de que nos sirve saber que el

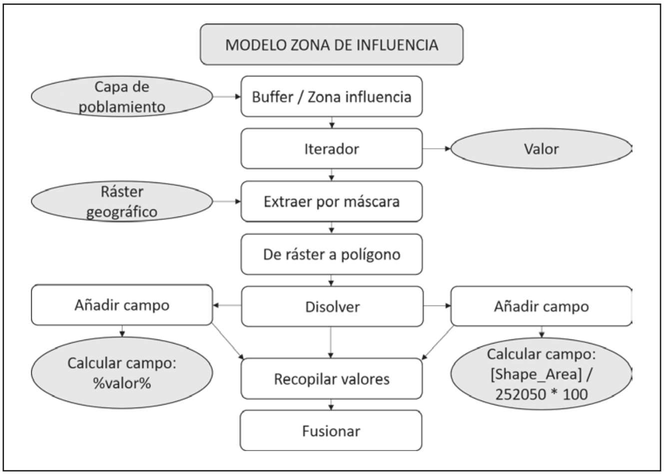


Fig. 2 – Esquema de herramientas utilizados en el modelado de la zona de influencia con Model Builder.

complejo edilicio está en un suelo u orientación determinada? Nos interesaría conocer que la *villa* cerca tiene un espacio muy bueno para viña o similar.

Ante esta cuestión, hemos desarrollado un método que se expone a continuación, de forma que se puedan asociar los usos agrícolas alrededor del yacimiento con el mismo. Como no conocemos el territorio real de cada *villa* como finca, hemos optado por usar un área de influencia, buffer, que se corresponda con un valor medio del territorio. Usamos una medida de la distancia entre las villas, que sí conocemos, y que coincide aproximadamente con el tamaño de una centuria, lo cual sería un radio alrededor de la *villa* de 283 metros. Este es un número que debería modificarse dependiendo de la densidad de yacimientos en cada caso de estudio.

El método de zona de influencia (Fig. 2) parte de tener una serie de elementos como es una capa de poblamiento y un ráster con criterios que se generaría en la fase anterior. Para simplificar el proceso usamos la utilidad Model Builder de ArcGIS que permite interconectar distintas herramientas. Con ello se hace un buffer, en nuestro caso de 283 m y se usa un iterador. Esta es una herramienta que selecciona cada área de influencia independientemente, en base a un valor, que puede ser la numeración de nuestras villas. Tras ello se extrae de cada zona de influencia los datos del ráster geográfico que queremos, de forma que aparecerá un recorte del mismo con el área deseada. Esto está en formato polígono por lo que se transforma a ráster y se utiliza una herramienta de disolución. Esta unifica los fragmentos de polígono en base a su valor en una misma entidad. Tras esto se añaden dos campos y se

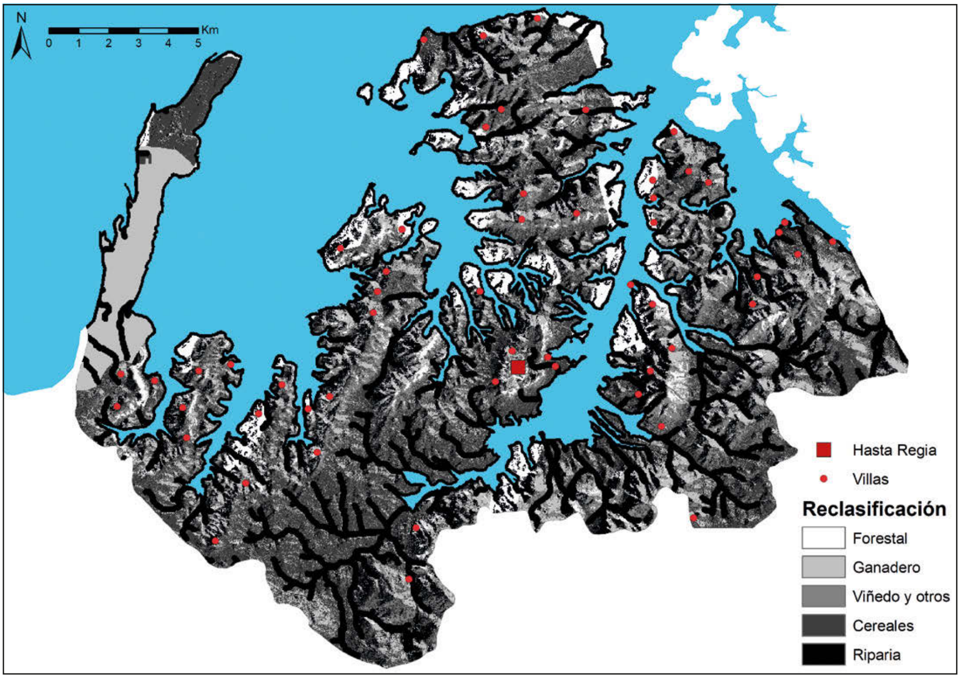


Fig. 3 – Mapa con la reclasificación de los distintos usos agropecuarios en la zona de estudio.

usa la calculadora en ellos. En el primero se devuelve %valor%, que se corresponde con el número del yacimiento original, con objeto de poder relacionar los datos posteriormente. En el segundo, se una *fórmula*, que es una simple regla de tres, para sacar el porcentaje de cada tipo de aprovechamiento entre el total del área de la zona de influencia. Finalmente se recopilan los valores y se fusiona todo en una misma capa.

El resultado, es que para nuestra capa original de poblamiento habremos sumado unos campos que indican el tipo de aprovechamiento agropecuario existente y el porcentaje en que están representados.

## 3. Resultados

En nuestro caso de estudio en la colonia de *Hasta Regia*, contamos con 53 *villa* analizadas. Conocemos los materiales asociados a las mismas, por lo que sabemos los que tienen indicadores de producción vinaria, pero dejaremos estos datos para la comparativa al final. Con el método asociamos los valores agronómicos con la geografía actual y volvemos a reclasificar dichos criterios relacionándolos a usos concretos. En este caso hemos tomado en

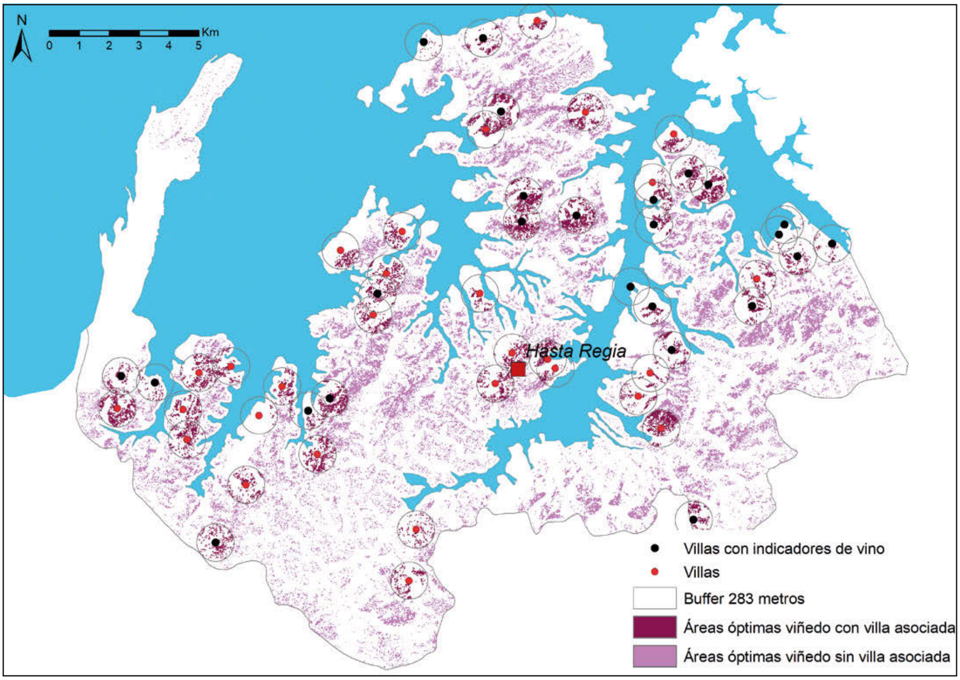


Fig. 4 – Áreas óptimas de viñedo en relación con el poblamiento villático e indicadores de producción vinícola.

cuenta cinco: riparia, forestal, ganadero, viñedo y otros árboles, y finalmente tierras de cereal (Fig. 3).

– Para el primer caso, hemos considerado como limitador la cercanía de espacios de riparia, de forma que todos los lugares serian óptimos en este aprovechamiento.

– En segundo lugar, se consideran los espacios para usos forestales o similares, con los que tienen una pobreza de suelo de cultivo y que se encuentren en una pendiente muy pronunciada.

– En tercer lugar, los espacios ganaderos pueden coincidir con los anteriores, pero también con lugares de colina o dehesa, media pendiente, pero que estén en suelos de tipo salino o intermedios para la agricultura. Igualmente se consideran aquí espacios umbríos al norte que no serían buenos suelos de cultivo.

– Un cuarto grupo sería el viñedo u otros cultivos similares como el olivo o frutales que podrían ser óptimos en suelos como los calcáreos (Trapero Fernández 2021b), orientados hacia el oeste por la cuestión del viento y a media pendiente.

– Finalmente, los suelos para cereal y cultivo general serían fundamentalmente zonas planas, con suelos buenos.

Con el modelo de zona de influencia, relacionamos esta capa de cinco valores con los distintos yacimientos, para conocer el porcentaje de representación que tiene cada uno. Así podemos saber los potenciales usos de un yacimiento, no solo en el caso de la viticultura, sino para otros también. Específicamente sobre el vino, en la figura anterior se selecciona el valor idóneo de este cultivo y se separa los espacios que están dentro de las villas y los que están fuera. Además, como conocemos los indicadores vinícolas, se expresa las villas que tienen estos valores, como puede observarse en la Fig. 4. El resultado es relevante pues la mayoría de los indicadores coinciden, siendo los casos donde no menores. Ciertamente en nuestro caso podríamos pensar en otras producciones como aceite, pero no existen registros arqueológicos de ello en la zona (Trapero Fernández 2021a). Además, el mapeado muestra una clara disposición de las villas en áreas con este potencial aprovechamiento, quedando huecos también óptimos. Estos son espacios preferentes para realizar prospecciones arqueológicas en busca de vacíos de investigación.

## 4. Discusión y conclusión

El método empleado permite tanto trasladar criterios antiguos a geografía actuales y asociar áreas potenciales de aprovechamiento, así como relacionarlos con yacimientos arqueológicos concretos. Pero el potencial mayor está de cara a la capacidad predictiva, dado que esta correlación muestra determinados patrones, como se puede ver en la Fig. 4. De esta forma podemos fácilmente comprender si los yacimientos, por ejemplo, cuentan con un área óptima de viñedo o similar. La cuestión aquí es que esto en un único yacimiento puede ser casual, pero sí parece representado en varios, nos permite establecer patrones, informándonos si es distinta la tipología de yacimientos, sus usos o incluso prediciendo otros donde se den condiciones similares.

Por supuesto, el método empleado parte de una relación de parámetros que clasificamos en base a los usos potenciales. Esta valoración puede ser parcialmente subjetiva, lo mismo que el área de influencia óptimo a utilizar. Para remediar esta cuestión, siempre se toman criterios agronómicos antiguos. También pensamos que el mayor desarrollo de estas herramientas hará que se pueda contrastar la idoneidad o no de unos u otros criterios, por lo que es importante difundir y realizar análisis similares y compararlos.

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ABSTRACT

GIS modelling of Roman viticulture is possible because we have information on production methods from ancient agronomy. The correlation between criteria and actual geography is possible. The problem arises when relating archaeological sites to these spaces, since we usually know only the farmhouse but not the area it occupied. This article firstly shows a method, to classify a territory according to the potential ancient agricultural and livestock uses. Secondly, an area of influence of such processes is shown to relate them to archaeological sites. The result is applied to a specific case study, the Hasta Regia colony, to demonstrate the potential of studying the landscape and predicting archaeological areas of ancient uses.

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# SHAPING A JURIDICAL DISTRICT: A POSTDICTIVE APPROACH

## 1. Introduction

This paper focuses on a GIS-based procedure to draw juridical boundaries of a given central place. Our case studies are a castle and a town in the Early Middle Ages. However, the procedure can be reproduced for any site, whose role as central place within a district is proven. This is not a brand new idea. Several attempts have been made over time, starting from the application of the Voronoi maps. This approach is helpful to get a rough idea, as I have shown for the late medieval Tuscan bishoprics (Citter 2012, 92-101). But it is deterministic and it does not consider natural as well as human agents that could have played a key role in shaping the historical boundary. Ten years ago we tried to calibrate this odd by redrawing the district according to slopes and hydrography. Now we can go further and try to link the simulation to more accurate morphological and hydrological models.

In particular, we aim to move to a postdictive approach. Sometimes, we already know the district's shape in a given period. But this is not always the case. In fact, sometimes we have no idea of its extension. The two case studies we provide here fall within both the former and the latter category. In the case of the town of Lucca we know the extension of its district in the 11th century CE, while the jurisdiction of the castle of Selvena is unknown. In the first case our procedure will aim to find the best approximation, such as a polygon, whose shape fits well with that of the historical boundary recorded by the sources.

On the contrary, in the case of Selvena we don't know the district. However, we can get some hints with a regressive approach. It has been hypothesised that the communities' districts drawn in the historical cadastre of 1823-1835 (also known as Lorena's cadastre: http://www502.regione.toscana.it/castoreapp/) are the outcome of the union of medieval castles' territories (Farinelli 2007, 23). We assume that this is true and we get the cadastre as a hint to compare the evaluation's outcome, though the precision's degree won't be the same as for Lucca.

A juridical district is influenced by several natural and human agents that reshape it over time. It is the result of a complex and long lasting process of political and economic negotiations, conflict, adaptation among neighbouring communities. Castles can be abandoned and their territory can be distributed among the neighbouring communities. A town normally started with a small district that became a regional state like for instance

Florence and Siena. The site catchment area is, thus, a different concept. This procedure is not intended to search for it. The expansion of Lucca beyond its town's walls was not welcomed by the surrounding lords and communities. The making of a castle district, as in the case of Selvena, is part of a wider process of seigneurial power. In this case the local community had little chance to influence the lord's decision. But, as we recently suggested (Citter 2021), it is likely that the community of Selvena used to live in small villages around the castle, rather than within its walls. The postdictive approach seems to be a wise choice to avoid both determinism and generic assumptions. It points out the potential agents that returned the district recorded by the sources.

We used to apply this approach to the connectivity network (Citter, Patacchini 2018), to the settlement location (Citter 2021) and, recently, to the symbolic landscapes (Citter, Paciotti 2023). Though the study of the movement has played a crucial role in the development and test of this approach, the last test and the present proposal open a methodological reflection toward a wider scenario and allow the GIS-based modelling to make significant step forward. In fact, in these last two cases the "traditional" topic of spatial analyses is less relevant from an historical perspective. The GIS is, thus, a laboratory where we can set new links to anthropology, law sciences, as we already did with earth sciences. The outcome of this paper, mainly in the case of Selvena, is not assumed to be the truth, but it is the best approximation we can draw today. If we will extend this approach to a large number of neighbouring castles, the aberration factors will be calibrated one another, due to the greater amount of data concerning boundaries that literary sources provide. Therefore, the single case study could find a more proper and a more accurate description.

C.C.

## 2. The two case studies: the procedure and the outcomes

As mentioned in the previous paragraph the study addressed two areas, the first one concerns the city of Lucca, in the North of Tuscany, while the second one refers to the castle of Selvena, in the southern part of the region. The study of these two areas involved a procedure that in a first phase is common to both to obtain possible districts. Once the possible jurisdictions were obtained, they were compared with the available data. To obtain the basins for the two areas we used DEM, Digital Elevation Model made available by Tinitaly (Tarquini *et al.* 2007), to which it was applied the SAGA algorithm TPI Landform Classification. It classifies the DEM's cells according to a list of 10 morphological positions (Brogiolo, Citter 2018). Thus, a morphologically accurate raster is obtained. We also applied the algorithm SAGA Wetness Index to the DEM. It evaluates the slope in a given point and the catchment area that passes through that point (Llobera, Fábrega-Álvarez, Parcero-Oubiña 2011; Brogiolo, Citter 2018).

Both rasters were reclassified in order to answer our question: how much do these characteristics impact in the formation of a jurisdiction? To reclassify the TPI we used the following rules: 1 thru 1 = 50; 2 thru 2 = 20; 3 thru 3 = 30; 4 thru 4 = 20; 5 thru 5 = 10; 6 thru 6 = 0; 7 thru 8 = 30; 9 thru 9 = 20; 10 thru 10 = 10. While the TWI was reclassified according to these rules: 1 thru 4 = 0; 4 thru 10 = 10; 10 thru 13 = 40 (Citter 2019). Then, we based on the reclassified TPI and the TWI to evaluate the least cost path. This is a raster in which each cell represents the energy needed to pass through it (Cross 2012; Verhagen, Jeneson 2012). The raster calculator is the mandatory step to get it. We need to assign a value to the characteristics that we want to take into consideration, in our case the morphology and the hydrology, represented by the reclassified TPI and the TWI. The weight assigned to the rasters must return a value 1 (Citter, Patacchini 2018). In our case we gave the morphology a weight of 0.6 while the hydrology 0.4. Thus, the raster calculator formula is:

TPI reclassified * 0.6 + TWI reclassified * 0.4

To this raster the algorithm r.walk.points was applied, to get a cumulative cost surface. Then, we run the GRASS algorithm Channel network and drainage basins to get the hypothetical districts.

To obtain the cumulative cost surface, the first case study used a vector file with the castles that are located within a radius of 20 km from the city of Lucca. We opted to consider the development of the city related to the control of the surrounding castles and in their districts. Concerning the case of Lucca, Voronoi maps have been made centred on the castles mentioned above. They show the potential catchment area, which does not take into account the geographic, political and institutional features of a territory. Thus, they are an abstract evaluation (Citter, Arnoldus-Huyzendveld 2011; Citter 2012). These polygons were overlapped to the basins obtained through the Channel network and drainage basins algorithm. The two layers closely overlay one another. In addition to this, the overlap with a vectorial layer of the jurisdiction of Lucca was also made. It was drawn by J.A. Quiros Castillo from a document dated to 1081 AD. In this chart it is said that the emperor granted to the city a territory of six miles around it (Quiros Castillo 1999). It seems clear that in a first phase Lucca's jurisdiction was based on the natural characteristics of the

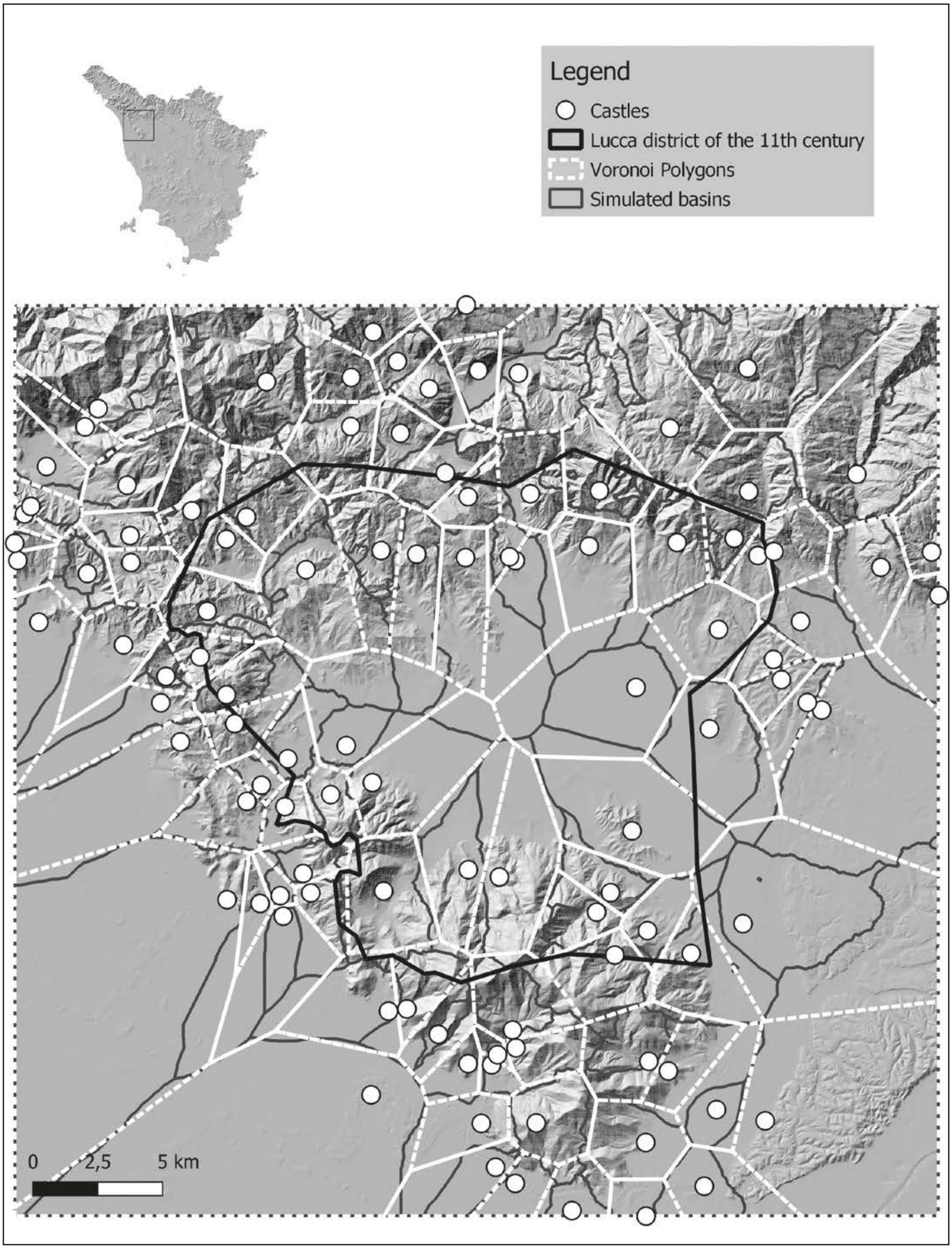


Fig. 1 – The case study of Lucca. In this image there is the overlap between the simulated basins (grey lines), the Voronoi polygons (white lines) and the Lucca district of the 11$^{th}$ century (black lines).

landscape, controlled by the castles and their districts, which we obtained with the QGIS simulations (Fig. 1).

The other case study took into consideration the area of the castle of Selvena, in Southern Tuscany. This area was important during the Middle Ages, for the presence of ore, especially cinnabar. To obtain the basins we applied the same method used for Lucca. We assigned to the TPI and the TWI reclassified a weight of 0.6 and 0.4. We assigned a higher value to the morphology, due to the landscape, which is predominantly a mountainous area. To the least cost path was applied the GRASS algorithm r.walk.points, but we included the castles located in the area we considered. Finally, GRASS algorithm Channel network and drainage basins has been applied to the cumulative cost raster, with that we obtained the hypothetical basins of the castles.

This raster has been overlain with a layer, that shows the boundaries of the community recorded in the historic cadastre of 1835, which Tuscan region made available through a WMS service. Before making an assumption, we must consider that the algorithm assigns to all the castles the same value, but it was not like that. We noticed that there is a high degree of overlap between the two layers and it makes us think that the nineteenth-century jurisdictions were a sum of the district of medieval castles. This theory has been hypothesized but never proved. At the end of the process we redesigned the district of the Selvena's castle, including the modern inhabited centre and the ore that were part of it but the algorithm inserted them in another castle district, which, we know, did not have the same importance as Selvena. To draw the district we followed the boundaries of the cadastre, including the aforementioned mines and the inhabited centre. The result is the best approximation ever made for a district of a castle, apart from cases where the boundaries were well known from the written documents (Fig. 2).

Y.P.

## 3. Conclusions

In this study we used the postdictive method, thus we run several simulations until we get the best overlay with the available data. Our case studies were focused on the city of Lucca and the castle of Selvena. The procedure we used took into account the use of natural parameters as morphology and hydrology, which returned good outcomes. Thus, we can say that the natural characteristics of these territories were important for the making of their jurisdictions. But we must take in consideration that where there is no overlay, it is obvious that there are other factors which influenced the formation of the boundaries. They can be either political or economic.

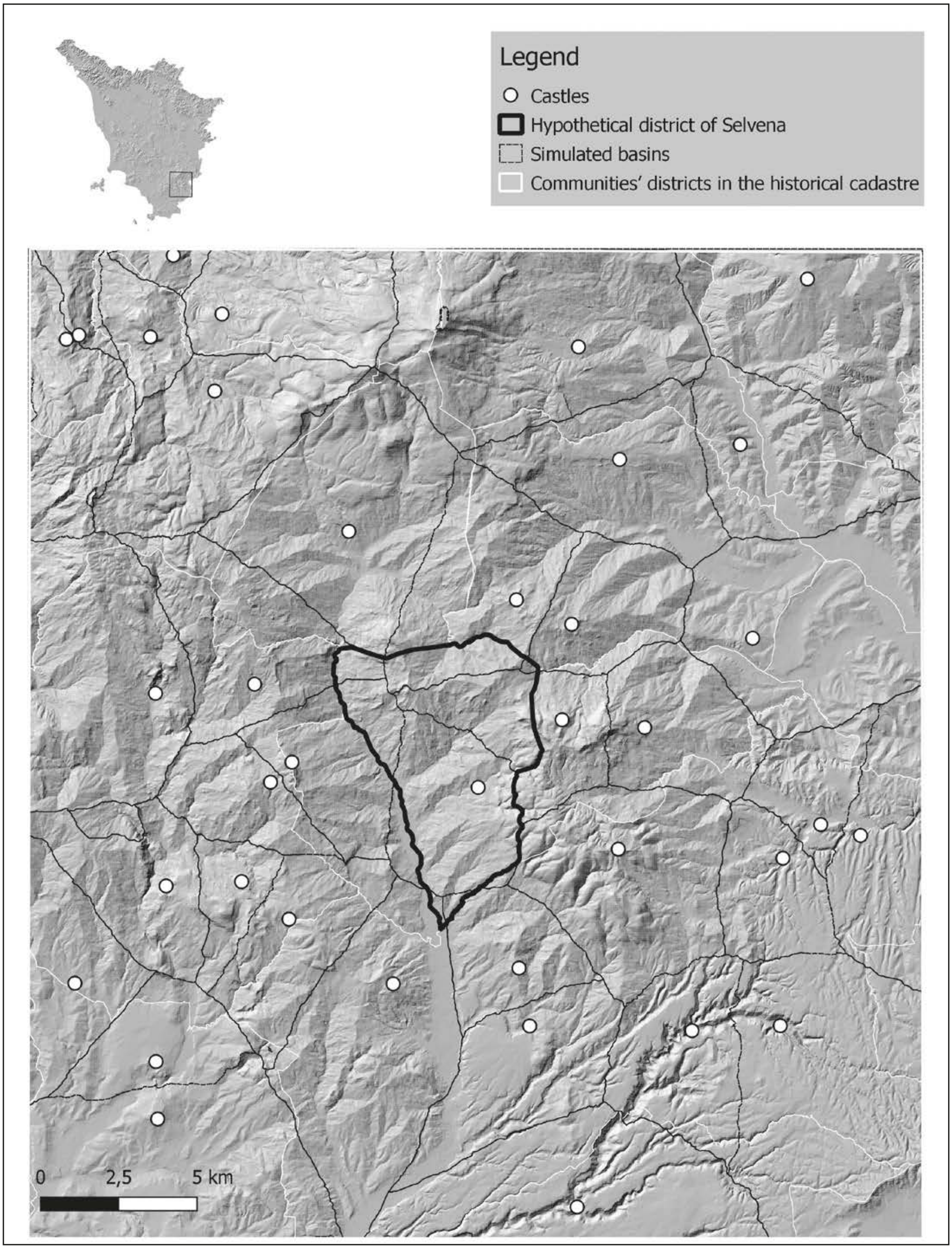


Fig. 2 – The case study of Selvena. In this image there is the overlap between the simulated basins (grey lines), the community districts in the historical cadastre (white lines) and the hypothetical district of Selvena.

Obviously, we will never have a perfect overlay between the simulations and the known data. There are many combinations of factors that could influence and we can only try to find some of them.

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ABSTRACT

How can we study the making of a medieval juridical space? Which were the agents that affected more? We try to answer to these questions thanks to a postdictive approach. We applied the QGIS algorithms to model the potential political space. We used several agents to get different outcomes. We tried both environmental and human agents to avoid the more deterministic side of this approach. We focused on the plain of Lucca in Northern Tuscany to study the making and development of its bishopric. Then we turned to the southern side of this region to study the district of a castle already excavated and whose territory is known quite well: Selvena. In this last example, we applied a regressive procedure, starting from the 19th century communities boundaries and making hypotheses about the relationship with medieval districts. This procedure can be applied to any context where a certain amount of data is available.

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# SPATIAL ANALYSIS AS A TOOL FOR FIELD RESEARCH. CASE-STUDIES IN PROGRESS FOR URBAN AND LANDSCAPE CONTEXTS

## 1. Introduction

This paper focuses on interpretation of historical landscape both at urban and territorial scale. It comes from an ongoing research, so the discussed processes and outcomes should be considered preliminary. Analysed case studies concern the evolution of a specific settlement or the detection of potential location for archaeological sites, above all when historical and archaeological data are not available (Arnoldus-Huyzendveld, Citter, Pizziolo 2016; Verhagen 2018; Verhagen, Whitley 2020). All the discussed instances have a similar methodological setting. A GIS dataset has been created and used to carry out spatial analyses; collected information come from different sources (above all excavations, historical maps, toponymy, medieval documents) and were integrated with geomorphological data to analyse settlement patterns and their diachronic relationship with environmental factors.

## 2. Urban contexts: backwards from the late(st) morphology

This section concerns urban contexts and the examined cases are Monselice (Brogiolo, Chavarria 2017, also for bibliography about previous researches) and *Salapia*-Salpi (De Venuto, Goffredo, Totten 2021). The first was a fortified early medieval settlement in the Euganean Hills (Veneto) and still exists today. The latter, Salpi, developed as a city in the 11th century and was abandoned during the early modern period. It occupied an artificial hill, superimposed on the western part of *Salapia*, a Roman city refunded in the 1st century BCE, along a coastal lagoon in Northern Apulia.

The object of the study is the hypothetical reconstruction of the medieval city (Monselice: Cardone 2017; Salpi: Goffredo, Cardone 2021) starting from the late urban morphology (Cardone, Giacomello 2018, 129-130). The analysis concerns the parcels extracted from the oldest geometric cadastre for Monselice (1810) and from the magnetic survey for *Salapia*-Salpi.

### 2.1 *Density of parcels*

Kernel Density Estimation (KDE) has been carried out to evaluate concentration/fragmentation of parcels. Lines (corresponding to boundaries

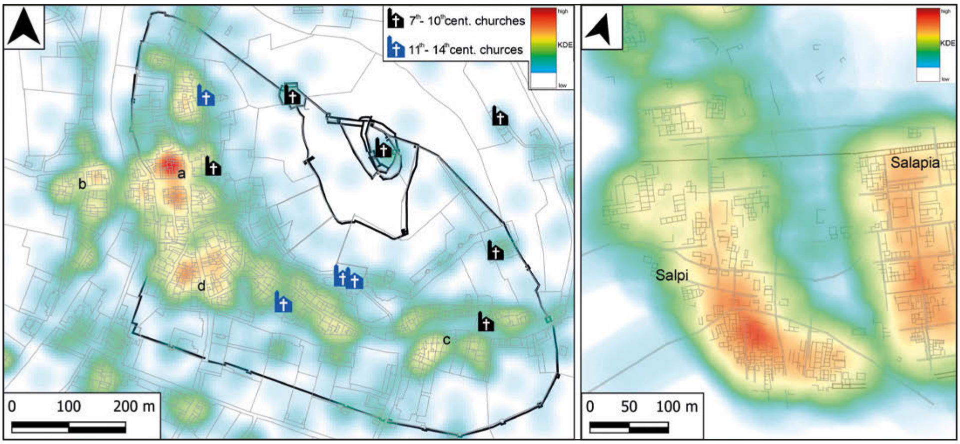


Fig. 1 – KDE in Monselice (left, based on centroids) and Salpi (right, based on lines).

of parcels) and points (centroids of parcels) density were estimated; no hierarchy of parcels has been assigned (so features do not have difference in weight) because very poor information about their functions are available. Density estimation highlights the difference between the northern and the southern districts of Salpi, according to the morphology shown by magnetic survey (Fig. 1). The southern district appears as a highly fragmented, residential area; excavations confirmed a gradual, intense occupation of empty spaces by dwellings during 13th and 14th centuries and their sizes suggest a planned subdivision (Goffredo, Cardone 2021, 306-309).

Instead, KDE returns a clustering structure in Monselice, represented by various concentrations, above all surrounding early medieval or 11-13th century churches. This result shows that older churches played a role as attractor of built-up lots and suggests a development of the city in the plane area by clusters, not still totally fused in 19th century. The concentration related to the main square (Fig. 1a) is expected for many reasons: that area was already occupied by a sector of early medieval Lombard settlement and the S. Paolo's church; it became the commercial (as the later Insula district; Fig. 1b) and administrative core of medieval and modern city. The eastern concentration (Fig. 1c) is likely a result of a long-term process: a local, isolated settlement near the S. Martino's church is hypothesized from 10th century documents, subsequently absorbed in the city. The southern concentration (Fig. 1d) is likely related to a node of viability rather than medieval churches; indeed, even if we cannot rule out a later development, converging roads could be a trace of a forced access (a bridge or a gate?) prior to Late medieval walls.

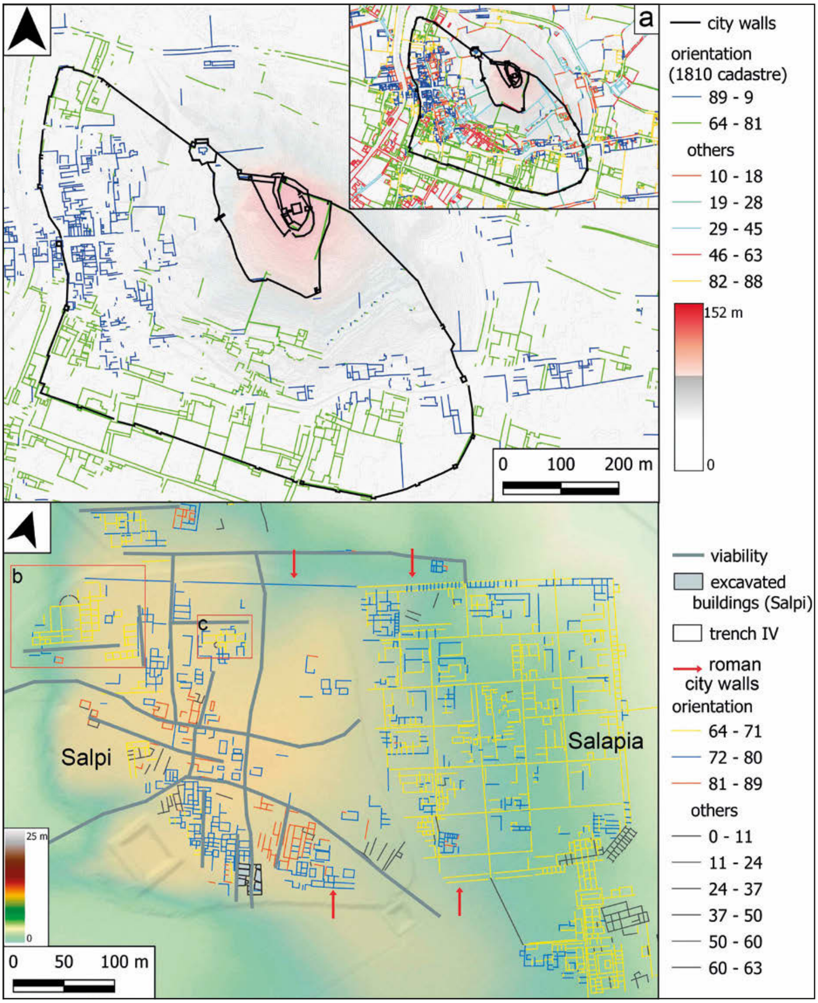


Fig. 2 – Main orientations of the urban fabric in Monselice (top) and Salpi (bottom).

## 2.2 *Orientation*

Orientation estimates have been carried out in order to find the relationship between the elements of the city (blocks of parcels, infrastructures, environmental features) and possibly their sequence. The analysis has been applied to lines (boundaries of parcels, buildings, rivers and canals, roads); just segments longer than 2 m were computed to obtain more reliable results. Tools used are EasyCalculate10 (ArcMap Esri 10.6); Azimuth in Field Calculator

(QGIS 3.16, 3.22); MorphAl, a plugin set for Alpage Project on Paris (https://alpage.huma-num.fr/gis-plugin/). Finally, orientation was reclassed to 0°-89° to group orthogonal lines as a single value; the range of values was obtained combining data from archaeological structures and Jenks natural breaks optimization. Used ranges group about 10°, but the high variability in urban contexts prevents the use of more narrow ones.

Two factors are affecting the orientation of parcels in Monselice. Firstly, orientation depends on geomorphology; values from NW to SE correspond to local slope direction, related to the Rocca (Fig. 2a). So, it prevents a general link between orientation and dating of parcels. Secondly, we cannot rule out chronological factors, because the main ranges are related to structured arrangements (Fig. 2). 89°-9° orientation interests an early medieval, settled area W to the Rocca, so this orientation could represent a previous arrangement which influenced the medieval phases (Brigand 2015 for a synthesis about the dynamics of transformation and transmission of the parcelling). 64°-81° orientation characterizes southern walls (13th-14th centuries) and nearby parcels, so we can easily suppose that it's a late medieval layout, when larger city walls were built. Dating of existing historical buildings is compatible with these hypotheses.

Different processes concern *Salapia* and Salpi. Obviously, the main orientation (64°-71°) corresponds to the arrangement of the Roman city (*Salapia*) and the total length of its lines is greater than the sum of other ones. Nevertheless, it is remarkable that some areas of the medieval city, Salpi, show the Roman orientation as well. Two districts (the western one corresponds likely to the cathedral) preserve the main orientation (Figs. 2b, 2c), while the central sector is oriented as the western sector of Roman walls (72°-80°); micro-orographic system caused this slight divergence of walls. We can suppose a strong preservation of (late)Roman layouts; this entails that the Roman city was not cancelled by the medieval artificial rise of the hill and excavations confirm a quite thin thickness of the 11th century fill (Goffredo 2021, fig. 12). Nevertheless, we cannot rule out a secondary, destruction hypothesis; the (late)Roman structures partially remerged after a levelling carried out during the last decades in some areas of the hill.

## 3. Dynamics in the historic landscape

Other notes are related to landscape scale; they concern the Northern Apulia and preliminary presented analyses will be further supplemented. They aim to analyse the landscape patterns in Daunian Mountains and Gargano, focusing on the post-classical period. The initial steps have been the detection of landform and high flood risk/marsh areas to determine the first parameters for favourable locations of ancient settlement (Citter, Patacchini 2017 and

Citter 2019 as a model for these applications to archaeological contexts). QGIS 3.22.0 tools (including Grass and Saga) have been tested to calculate landform (Topographical Index-TPI: Weiss 2001; Geomorphon: Jasiewicz, Stepinski 2013) and water accumulation (Wetness Index-TWI: Mattivi *et al.* 2019). Unfortunately, just 10/20 m DTMs are available for the whole examined area.

### 3.1 *Landform*

The first case study concerns the area between Daunians mountains and Lucera (Foggia). Slightly raised plateaux delimited by fluvial incisions mainly characterize this territory. Alluvial, terraced deposits covering sub-apennine clays constitute the upper part of plateaux and higher hills; they result intensely occupied. Basic settlement choices are quite evident, based on the known archaeological sites. In the Middle Age, cities occupy highest hills mainly as requirements for defense and control; quite the opposite, our knowledge of minor sites is still scanty. So, the first aim was the detection of possible locations for rural sites known from sources (usually indicated as "casale", an open and not independent settlement).

Used tools are TPI (10 ranges from two maps with different radium) and Geomorphon (Fig. 3a-b). A selection of highly positive values from TPI has been considered because, even if it is not formally corrected, it results useful to accurately detect low-raised plateau, otherwise reclassified as part of wide, flat areas. Slight difference in heights complicates the setting of starting parameters.

The selection of raised elements (Fig. 3c) mainly corresponds to elongated uplands; these are hills similar to those on which Montecorvino and Tertiveri stood (cities likely founded in the early $11^{th}$ century: Favia, Giuliani 2022). This selection accurately includes known medieval sites (both cited cities and sites for which we know location from sources, e.g. Guardiola). Some small reliefs stand out as potential abandoned settlements (as they share features with other archeological sites, i.e. flat summit, terraced levels, isolated location) and will be verified by aerial and field survey. Moreover, a series of low but pronounced reliefs between Montecorvino and Lucera is comprised within this selection; some dependencies of Montecorvino (the casale of S. Lorenzo de Rivo Morto and two estates related to churches of S. Paolo and S. Nicola, cited in documents from $13^{th}$ century; Martin, Noyé 1991) were likely located in that area (Fig. 3d), as suggested by historical cartography and toponymy.

We must point out that traditional sources do not provide enough data to exactly locate these settlements; described boundaries of the estates in these documents are very difficult to be georeferenced, while modern maps just report some toponyms without the location of the medieval settlements. TPI

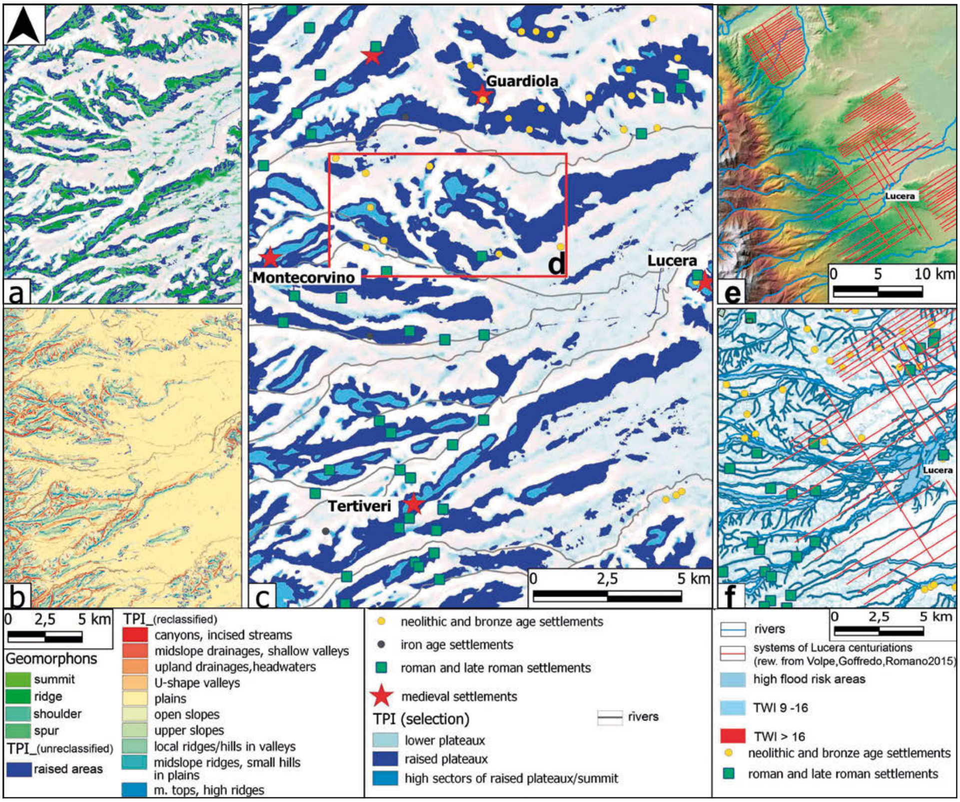


Fig. 3 – The area between Lucera and Daunian mountains: landform (a: raised zones from selection of geomorphons and unreclassified TPI; b: reclassified TPI); settlement pattern (c) and the area of the reliefs between Montecorvino and Lucera (d); centuriations (e) and hydrologic system (f).

instead helps us to overcome the lack of traditional sources and it is useful to narrow down searches in the wide space deduced from maps and toponyms. This process allows us to identify specific areas to be verified by field survey: TPI defined an area of about 148 ha within a space of about 2765 ha extracted from toponymy and cartography. Moreover, the ongoing publication of surveys carried out by Ager Lucerinus Project (Marchi, Muntoni 2018) will add new information for this area and for comparison between spatial analysis and archaeological data.

### 3.2 *Hydrographic network*

TWI index allows a further evaluation of potential areas for settlement. Discussed examples, however, take into account recent alterations of landform

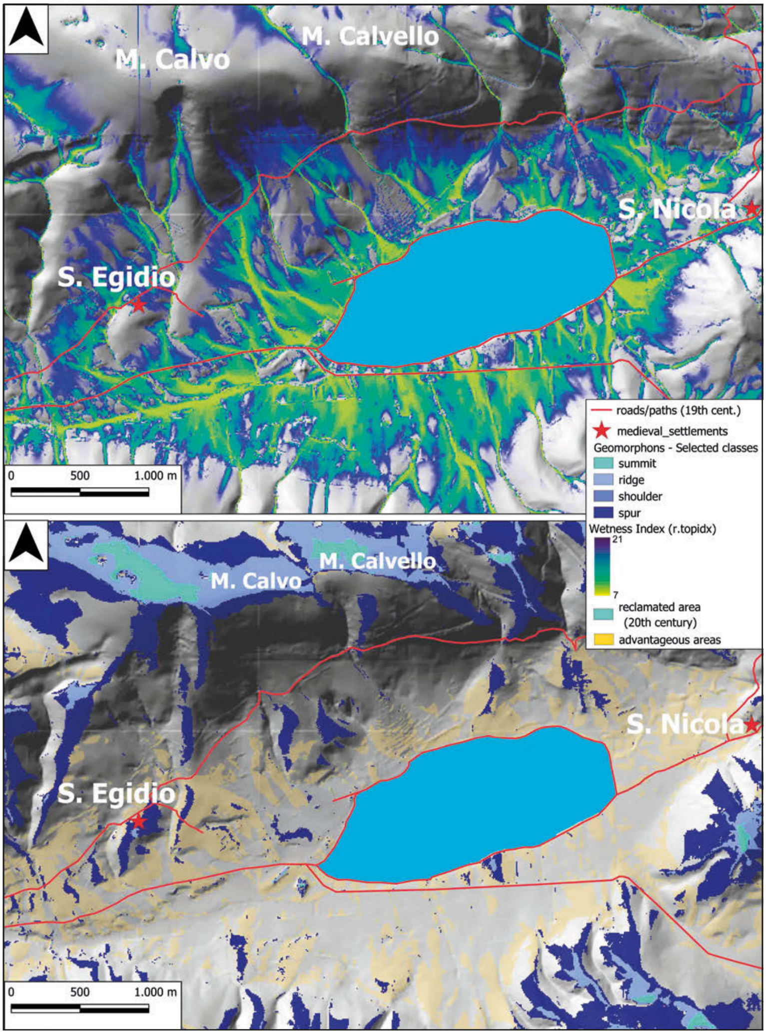


Fig. 4 – The area of S. Egidio: TWI (top) and favorable areas (bottom) for the medieval settlement (raised or low slope/wetness areas).

and reclamations, in order to provide an interpretation not exclusively applied on current DTM. Some examples concern the Gargano promontory. In the central area medieval settlements are mainly located along the EW fault that crosses the massif. They often occupy the upper slope of this valley system, where a dense network of torrential streams flows (locally called *lame*) and caused flood phenomena and local swamps still in 19th century. So, the

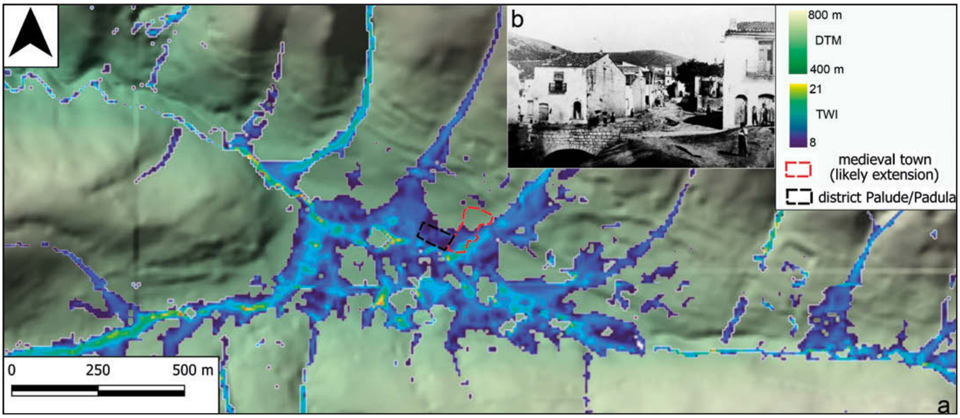


Fig. 5 – a) S. Marco in Lamis, TWI ; b) unpreserved bridges in *via Lungo Iana* (Tardio 2010, 6).

reconstruction of hydrological network is a very important factor to detect unsuitable portions of territory and to create cost surfaces.

At first we consider the area of S. Egidio (Fig. 4) near S. Giovanni Rotondo, where a lake (*pantanum S. Egidii*, more likely a mere or a large pond; Martin 1994) occupied a carsic depression, produced by a sinkhole and pull-apart movements; it was reclaimed at the beginning of last century. In the late 11th century the S. Egidio monastery was built on a spur facing the lake. A hamlet and agricultural fields developed there between the 12th and 13th centuries, but their exact location is unknown. The overlapping of TPI and TWI maps help us to detect potential areas for these elements, because high hydrological risk and geomorphological instability affected this region. Indeed, the runoff waters coming from northern reliefs gather there and documents probably imply a formation of the lake during 11-12th century, while its surface was probably frequented before the Iron Age (Monaco 2017, fig. 3). So, a considered favorable area (Fig. 4) consists of raised zones nearby the monastery, selected by TPI, and zones characterized by low dampness (to avoid hydrological risk) and low slope (otherwise unsuitable for farming use); slope <20% and TWI <7 have been considered in the final raster.

A short consideration concerns S. Marco in Lamis (Fig. 5). The city is reported since the early 11th century; it developed on the northern slope of a valley, while the bottom part was interested by a river (Iana) and a swamp produced by the torrential rivers (locally *lame*) that cut through the slope; they both were buried in the last two centuries. In that sector TWI correctly returns an elonged zone characterized by high values, corresponding to the river, and a wider sector characterized by the accumulation of waters. In these case historical pictures (they report at least two disappeared bridges in the early 20th century; Fig. 5b) and toponymy (the existence of a swamp at the foot of historical center is proved by the toponym "palude" or "padula" for the district facing the lowest sector) provide a validation of TWI results.

### 3.3 *Notes for the future work*

Other synthetic remarks come from combination of TPI and TWI analysis as a tool to underline different criteria for settlement choises and a delimitation of potential exploited territory in a diachronical, long-term analysis. They concern the ongoing development of previous notes and will be presented shortly. The examined area is between Daunian mountains and Lucera (Fig. 3e-f). Here the neolithic settlements (Hamilton, Whitehouse 2020) mainly occupy the raised plateaux, often their edge overlooking (paleo) fluvial incisions. Moreover, their location implies a significant stability of the geomorphologic landscape in this region. They avoid high-risk flood areas and their location frequently corresponds to very low-TWI (<2, Fig. 3e) spaces delimited by higher TWI values (>9, Fig. 3e). This is a useful criterion to be implemented into a multicriterial predictive research for neolithic sites in this region (already carried out projects are Danese *et al.* 2014; Dufton 2021), above all to balance the distribution of known sites.

They have been mainly detected by cropmarks (where the ditches of the villages cut the local *crusta*, a surface, carbonate layer), but systematic field surveys show a scattered, Neolithic presence even where the aerial photos are less effective. In a later phase, flood risk areas do not strongly affect the distribution of Roman sites, located in the low flat zones in addition to raised terraces; moreover, the cropmarks related to Lucera centuriation (Fig. 3e-f; a synthesis in Volpe, Goffredo, Romano 2015, 475-488) are visible in areas characterised by high TWI values. This wider exploitation of territory is a conceivable consequence of the hydraulic arrangement carried out by the centuriation (Dall'Aglio 2010 for this subject), in addition to a lower weight of the defensive factor.

Finally, TPI allows us a more detailed detection of the framework related to the medieval settlement and to the fortified frontier arranged by the Byzantines in the early 11th century (Favia, Giuliani 2022) in particular. TPI highlights an alignment of ridges as a watershed between Lombard and Byzantine settlements in the 10th-11th century according to written sources. Furthermore, it could suggest an organic planning: the Byzantine cities occupy the reliefs towards the plain; various sites in the highest area (reported starting from the late Middle Ages or the beginning of Modern Age) have a relevant location to this frontier and its crossings places. So, we cannot rule out that these sites have a coeval foundation to the frontier (outposts then developed as settlements?); therefore, the verification of their starting chronology becomes an important research objective.

## 4. Conclusions

A brief remark concerns an evaluation of patterns by GIS computation; it is not essential for some examined cases (i.e. districts with diverging macro-orientation or reliefs as potential sites, visible in DTM), but the automatic detection enables a work that is difficult to replicate in terms of quality (e.g., the small differences in orientation for Salpi), as well as producing an effective and fast outcome on large areas by comparison with a visual process carried out personally by the researcher.

Moreover, the analysis performed often combines retrogressive and predictive considerations; this depends both on the data available and on being an ongoing work. Available data are not sufficient and suitable to set an accurate, predictive process for most of discussed examples. A case in point concerns examined urban contexts compared to projects about medieval towns in Tuscany (Citter 2012; Gattiglia 2013), for instance. Published excavations in Monselice focused on the Rocca, but not the foothill area (except the zone near S. Paolo) where the medieval town center developed, while there is no previous research in Salpi.

In conclusion, the presented works aim for a dual purpose. Firstly, they intend to highlight key-points for the field research, to define areas «where to concentrate research efforts» (Verhagen 2018, 2) regardless of urban or landscape scale; it concerns above all contexts where traditional sources show a lack of data. Secondly, they aim to propose hypotheses on the diachronic evolution of contexts that cannot be investigated in a complete and exhaustive way, such as the abandoned cities for which a total excavation cannot be achieved.

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## ABSTRACT

This paper concerns spatial analysis applied to urban and landscape scale; main aims are the reconstruction of the evolution in a specific settlement and the detecting of potential location for archaeological sites. Spatial analysis takes advantage of a GIS dataset containing different systems of sources (excavations, historical maps, toponymy, medieval documents, geomorphological data). Case studies at urban scale concern Monselice (Veneto) and Salpi (Northern Apulia). A retrogressive analysis aims to reconstruct the medieval urban fabric starting from the late morphology of these cities, using the modern cadastre or a magnetic survey. The Kernel Density Estimation and the evaluation of parcels orientation have been applied for a comprehension of the urban structure. At territorial scale, case studies regard two sectors of Northern Apulia. First step of these ongoing researches concerns the detection of landform (by TPI-Topographical Index, Geomorphons) and Wetness Index (TWI). This work helps us detect potential areas for settlements which are not preserved (dependencies of the city of Montecorvino and of the monastery of S. Egidio) and validate the outcomes of TWI (S. Marco in Lamis); moreover, it provides new hints about the relationship between settlement pattern, geomorphological elements, territorial/hydrological arrangement related to centuriation.

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# HOW TO RECONSTRUCT THE HUMAN MOBILITY IN MOUNTAINOUS AREA. A CASE FROM NORTH-EASTERN ITALY

## 1. Introduction

Today, the reconstruction of mobility network is becoming a more and more important line of research, in particular in flat areas. Nevertheless, some scholars had already developed methods to study viability and mobility in mountain (Llobera 2000; De Silva, Pizziolo 2001; Fàbrega Alvarez 2006; Fàbrega Alvarez, Parcero Oubiňa 2007; Murrieta-Flores 2012). The majority of these ones had produced algorithms to draw Least Cost Paths, which represent the fastest and less costly path between two points. At the contrary, the intent of this research is to elaborate a methodology in order to obtain a mobility network, which consists in one or more nets of paths which run from a common point in all directions around it, describing a possible mobility grid that involves all the analysed territory.

In fact, the particular objective of this approach is to understand how many contemporary routes in an area follow ancient mobility halls and how much antique they are. The method adopted (Mascarello 2021) is based on the modification and compenetration of two other theories. The first one developed by C. Citter (2019), using algorithms for hydrographical analysis, the second one by P. Murrieta-Flores (2012), which adopted the Line Density Analysis to identify the level of accessibility of an area. The work presented had been developed in a small region in the Northeast of Italy, named Feltrino (BL), in a time frame that runs from the Bronze Age to the Contemporary. The goal was the identification of continuities and breaks in human mobility strategies between five different periods: Bronze Age, Late Roman (IV-VI centuries), Middle Age (XII-XIII centuries), Modern Age (XV-XVII centuries) and Contemporary.

## 2. Methodology

We first step with collecting all the historical and archaeological information about the analysed territory, selecting the better represented historical periods and creating maps of settlements and archaeological areas for each one using a GIS (Geographic Information System). Then, we select and map the natural features which could have better influenced human mobility: for example morphology (outlined through the algorithm TPI-Topographic Position Index), hydrography, slope, passes. In case of important changes along time, we could produce more maps for one feature. It is important to underline that the parameters need to be chosen every time, in relation with the characteristics of the region. The next passage consists in the creation of friction surfaces by reclassifying maps with the allocation of a series of weights. These run from 0 (no difficulty) to 70 (maximum difficulty). We do not use the score 100, because we really do not know the abilities of ancient people in moving through mountainous environment and what they perceive as unaccessible. Different strategies were applied to weigh maps according to their peculiarity.

For example, in a map showing dots, such as attractive points or passes, the application of Multi Ring Buffer (MRB) was useful to suggest the algorithm to attract or discourage the crossing. A different weight is attributed to each ring in order to encourage the crossing. On the contrary, in hydrography, rivers have the highest weight, while the rest of the environment has the smallest one, in order to underline the impossibility to go through the water without bridges. If the presence of some bridges is testified, they become part of the environmental base and assume its weight. Finally, in the TPI, weights are related to the geomorphological characteristics of the area while for slope their amount increase in relation with the rising of percentage of slope. When all maps are made, a weighted sum for every period considered need to be made, in order to create the cost surfaces, simply using the raster calculator.

These resulted maps are the bases to elaborate the cumulative cost surfaces. This method provides the application of the algorithm r.walk.points, in which we use as starting points the vector maps of settlements and arriving points are not considered. In this way, it would be possible to estimate the potential movement in every direction around each settlement. The cumulative cost surfaces represent the environment in which the potential paths networks run. They are generated by the application of another algorithm, Channels network and drainage basins, and start from selected points, that could be settlements or passes or some other types of sites. At the end, a map with some moving networks is obtained for every historical period analysed.

At this point, based on the works of M. Llobera (2000) and P. Murrieta-Flores (2012), we realised a Line Density Analysis through the application of the tool Line Density (available in QGIS from the version 3.16), in order to generate more general moving halls that could be easier to match, but also more likely to represent the human ability to move in their territory. The halls created represent the density of paths that are included in their width, which could be defined in relation with geomorphological characteristics. In our opinion, in relation with mountainous areas, it is better to use short range buffers because of the rapid variation of altimetry and geomorphological features. A map for each period has been produced.

Finally, we compare the Line Density maps created through both the sums of couples of them of consecutive periods and the sum of all of them, so that the common corridors are more visible. The first solution underlines continuity and breaks between two consecutive periods, the second one the continuity in the *longue durée*.

## 3. Case study

### 3.1 *Location*

The area of application and development of this method is a 215 square km region, named Feltrino (BL), in the Northeast of Italy (Fig. 1). Its territory is partially enclosed in the National Park of the Dolomiti Bellunesi and thanks to the variety of its landscape, it is resulted an ideal place. In fact, its morphology run from valley bottom to middle hight plateaus, on which were and are today located the majority of settlements, to upper glacial circles and mountainous peaks. The glacial circles, also named "buse", are basins produced by the erosion of the incoming of glaciers during the last Wurm Ice Age, between 75.000 and 12.000 years BP. The mountain range of Vette Feltrine, which characterised this area, have ever been a transit hall because of their location along the boundary between reigns, duchy, and today regions. And we have information about changes that occur in its environment along time, both from archaeological findings and historical sources and from geomorphological and hydrological researches. All the specificities indicated before became fundamental in the choice of this place for the application of this method.

### 3.2 *Application of the methodology*

Both historical and archaeological data, hydrological and geomorphological information about the Feltrino region had been collected and all had been mapped on a GIS platform. The platform selected was the open source

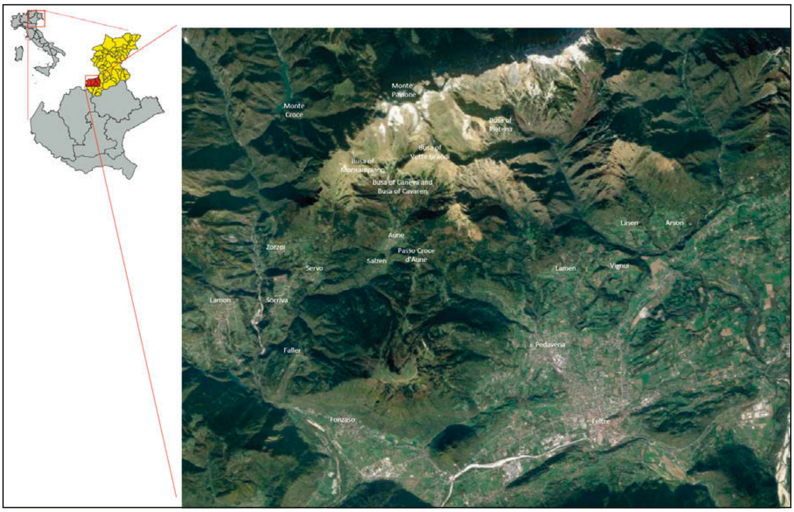


Fig. 1 – General view of the area of Feltrino (by C. Mascarello).

QGIS, in particular two versions: the 2.18 with GRASS 7.4.1 and SAGA 2.3.2, for the simplest elaborations, and the 3.16 implemented by GRASS 7.8.5 and SAGA 2.3.2 for the most particular ones. Some historical periods had been selected, due to the amount of information collected: Bronze Age, late Roman (IV-VI centuries), Middle Age (XII-XIII centuries) and Modern Age (XV-XVII centuries). We produced two maps for each one representing settlements and archaeological areas. Moreover, some selected natural characteristics were mapped: slope, hydrography, mountainous passes and morphology. All the maps were based on the CTR (Carta Tecnica Regionale, scale 1:10.000) and the DTM (Digital Terrain Model, scale 1:5000) available on the Geoportale of Veneto (https://idt2.regione.veneto.it/geoportal).

One of the main characteristics of this research is that it was developed on three different scales of work: the littlest one strictly involves the mountainous area of Vette Feltrine, the middle one is referred to the boundaries of the municipality of Sovramonte, the biggest includes all the Feltrino region. Based on the variable mapped, we built the cost surfaces. Firstly, the elements of every map were weighed, giving a score from 0 to 70 in order to indicate where the human movement could be easier or more difficult. Different methodologies were used: a score had been given directly to the element and another, usually of opposite amount, to the rest of the environment, for example for hydrology. In this case, rivers had the highest weight, while the rest of the territory, included bridges, had the lowest. In the maps with dots, for example archaeological areas or passes, we applied a multi ring buffer (MRB) to every element represented, in order to encourage the crossing, but not oblige it. Increasing scores were given to the rings starting from the central one, the closest to the point, whose weight was 0. This same rating was assigned to the base representing the rest of the territory. The third method, used for slope and TPI, consisted in assigning different weights where changings occur, for example, with the rising of the percentage of slope or with changing in geomorphological characteristics.

When all maps were created, a weighted sums of them for every period need to be evaluated, in order to create a cost surface. It could be done in the raster calculator, as exemplified:

TPI * 0.2 + mountain passes * 0.2 + hydrography * 0.2 + slope * 0.2 + sporadic findings * 0.2

These cost surfaces were the bases for the construction of the cumulative cost surfaces. This method provides the application of the algorithm r.walk.points of GRASS, where the maps of settlements were considered as starting points. Arriving points were not considered and the DEM (Digital Elevation Model) was the referring map for elevation. For all other parameters, the default data were maintained. On the cumulative cost surfaces, we applied the algorithm of SAGA Channels network and drainage basins. A map with some path networks was created for every period. We decided for a threshold of 6 and settlements resulted as starting points. The last step consisted in the application of the Line Density Analysis. For every analysed period, we created a map of networks of movement halls with 100 m of radius. As said before, the use of a short range buffer is due to the rapid change of altimetry and geomorphological features that occur in mountain. Finally, we compared the results obtained through both the sum of couples of maps of consecutive periods and the sum of all of them, to understand continuities and breaks in the hypothetical human mobility network in the Feltrino region along time.

### 3.3 *The change of the parameters in the function of r.walk*

A collateral test had been attempted during the elaboration of the cumulative cost surfaces. Some parameters of the function of the tool r.walk were modified, in order to try out a more reliable terrain model. It was also useful to understand if some changes occurred in channel networks compared with those obtained using standard parameters. In particular, the parameter b (additional walking time in seconds, per meter of elevation gain on uphill slopes, corresponding to +6 s/m; Langmuir 1984; Minetti 1995) were changed. We deduced the necessary steps from an article of the physiopathologist A. Minetti (1995), starting from the walking time in seconds and the elevation gain in meters, as in the example:

1. Speed calculation in m/s.
2. Changing from m/s to s/m.
3. Subtraction of the time that occur for walking 1 m in plan (0.72 s).

The data were acquired both from field survey and from some trekking sites about Vette Feltrine area.

### 3.4 *The field surveys*

Some field surveys had been organised in the upland of Vette Feltrine. They occurred in three days and allowed us to better understand the morphology of this area. Moreover, we explored and traced with a GPS some paths both already in use and abandoned, in order to compare these traces with the hall networks obtained. For the first day, we climbed to the Vette Feltrine through a 3320 m path with 1200 m of elevation gain, climbed in 2 hour and 50 minutes. The second day, we explored the "buse": we walked about 20 km in 6 hours, without important elevation changes. The last day we came down through a different path. We hiked for about 19 km downhill and in the plain for 4 hours and a half.

During these surveys, every human trace had been documented through some photographs. A little percentage of paths resulted from the creation of maps of channel networks had been verified. And some of the enregistered data were used to calibrate the parameters applied in the different elaborations described above.

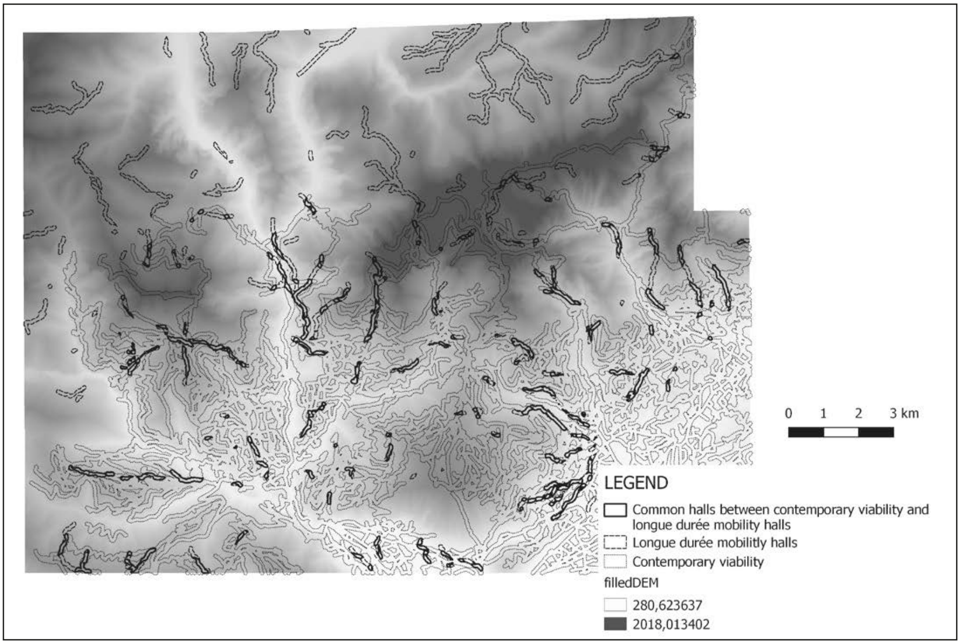


Fig. 2 – Contemporary routes in relation with the results of GIS elaborations. Dots lines correspond to contemporary viability, dashed lines represent the *longue durée* mobility corridors. Continuous lines draw paths resulted from the intersection between contemporary routes and the *longue durée* mobility (by C. Mascarello).

## 4. Conclusions and discussion

We compared the Line Density maps through both the sums of couples of them of consecutive periods and the sum of all of them, so that the common corridors are more visible. The second elaboration represents the *longue durée* and reveals a probable continuity along millennia of some of the mobility halls identified. They both climb from settlements to "buse" and passes and run between villages in the Feltrino valleys. Moreover, an overlay between this one and the contemporary street map shows several overlaps and a possible antiquity of some of the today's routes (Fig. 2). It is partially confirmed by the comparison with the Modern Age cartography, in particular the *Dissegno del Territorio di Feltre qual per comando dell'Illustrissimo et Eccellentissimo signor C.O.: Lodovico Flagini* of F. Grandis, dated to 1713 (Fig. 3) and the information from historical and archaeological sources.

About the changing of parameter b in the r.walk function, the most evident difference was a general upstream stretch of the paths: the higher the parameter b, the longer the channels. This phenomenon is due to the increase

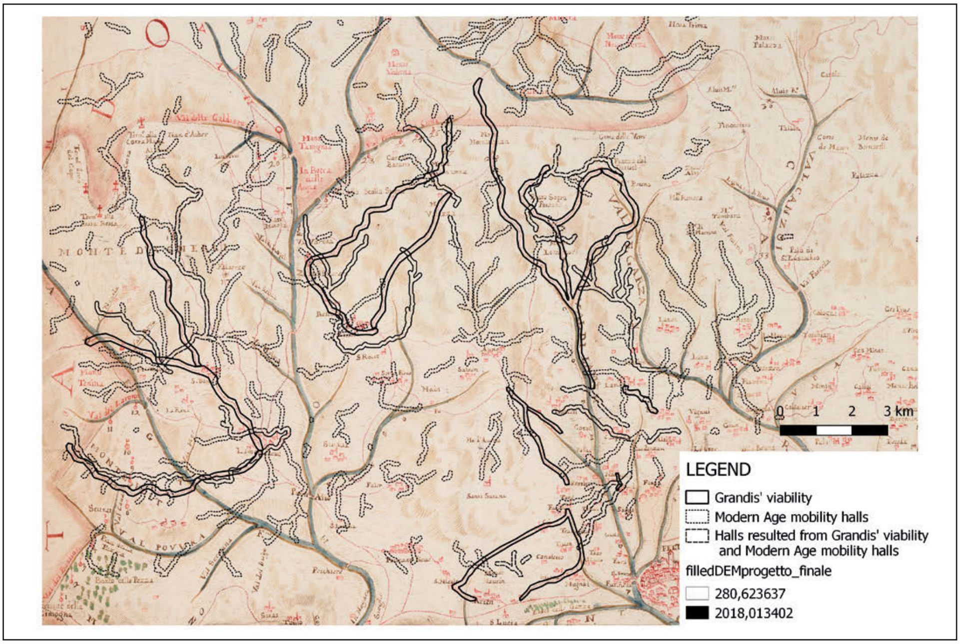


Fig. 3 – Continuous lines represent some tracks on the Francesco Grandis' map that could be compared with the Modern Age mobility corridors, indicated by dots lines. Dashed lines draw the mobility halls resulted by the comparison between Modern Age elaboration and Francesco Grandis' map (by C. Mascarello).

of areas with a less difficult transit, linked to a cheaper travel in term of physical costs due to the decrease of the speed during the hiking. Moreover, new paths resulted, in some cases with important correspondences with the viability on the CTR. No substantial shifts occurred in moving directions. All these results show that the morphology of mountainous environment strongly limits the corridors of transit and that the choice of a path is not influenced by the time, but by the necessity to gain the destination.

Obviously, we need to test the outcomes of these evaluations. We partially did it in the Vette Feltrine, though we still need to extend the survey. The main goal is now to re-trace the connectivity network, according to the evaluations and to check the intersections of the halls to test their archaeological potential. This approach can be applied to every mountainous environment, though the parameters should be calibrated.

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## ABSTRACT

The aim of this research is to define a new methodology in order to reconstruct the historical human mobility network in mountain areas in a perspective of *longue durée*. Through the match of different types of data, in particular historical and archaeological sources, the analysis of environmental features and the application of a series of algorithms on a GIS platform, we produced a series of maps of possible mobility networks. The comparison between them and with the historical cartography emphasizes both continuities and breaks over time and outlines the reliability of the elaborations obtained. Our focus is a small region in the North-Eastern Italy, called Feltrino (BL), on a time frame from the Bronze Age to the modern times.

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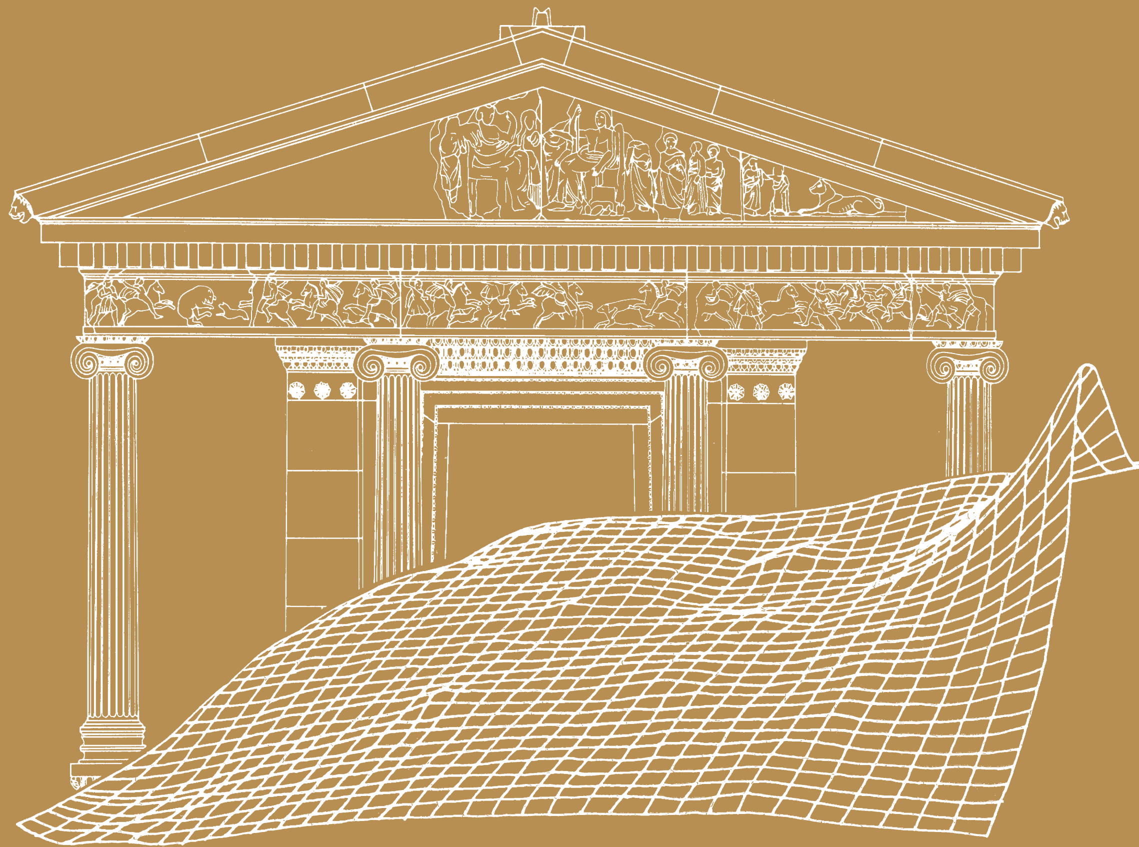

# ARCHEOLOGIA E CALCOLATORI

## 34.1

2023

*All'Insegna del Giglio*