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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.

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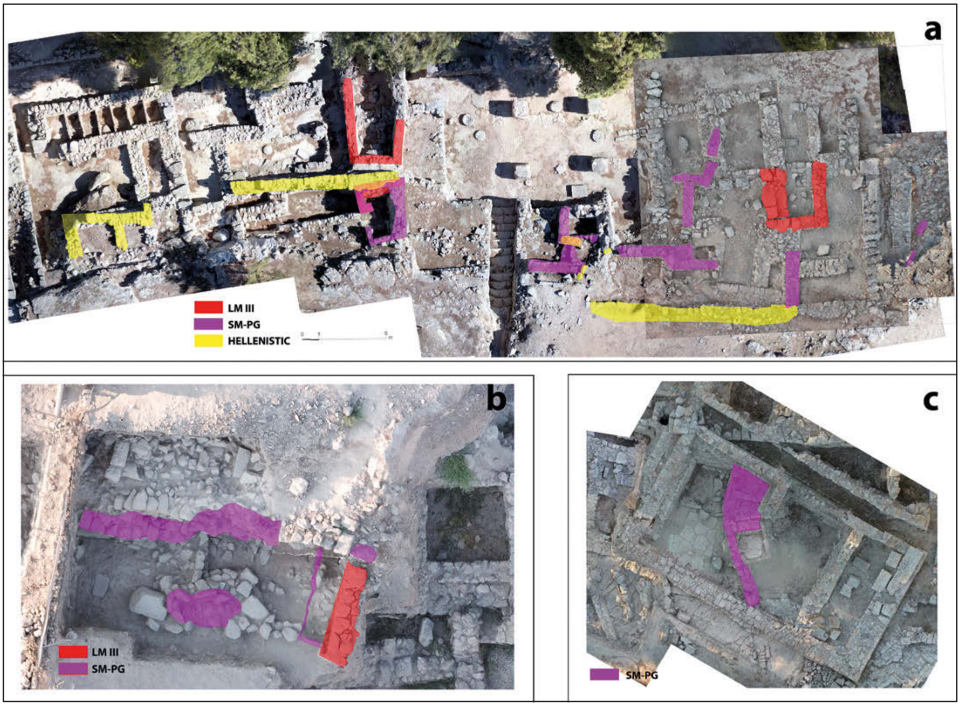

Fig. 1 – Phaistos, Post Minoan phases after the recent excavations by the University of Catania: a) NE Sector (2015-2018); b) Room NN (2022); c) so-called Temple of Rhea (2017) (orthophotos by F. Buscemi, M. Figuera, M. Spiridakis).

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

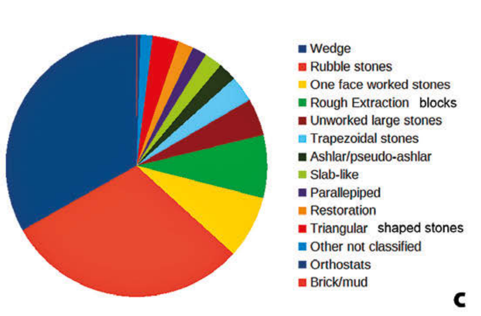

Fig. 2 – a) False color rendering of the stones according to their semantic classification; b) segmentation of the wall into wall facing stones; c) pie chart of the occurrence of the stone types within the sample walls.

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

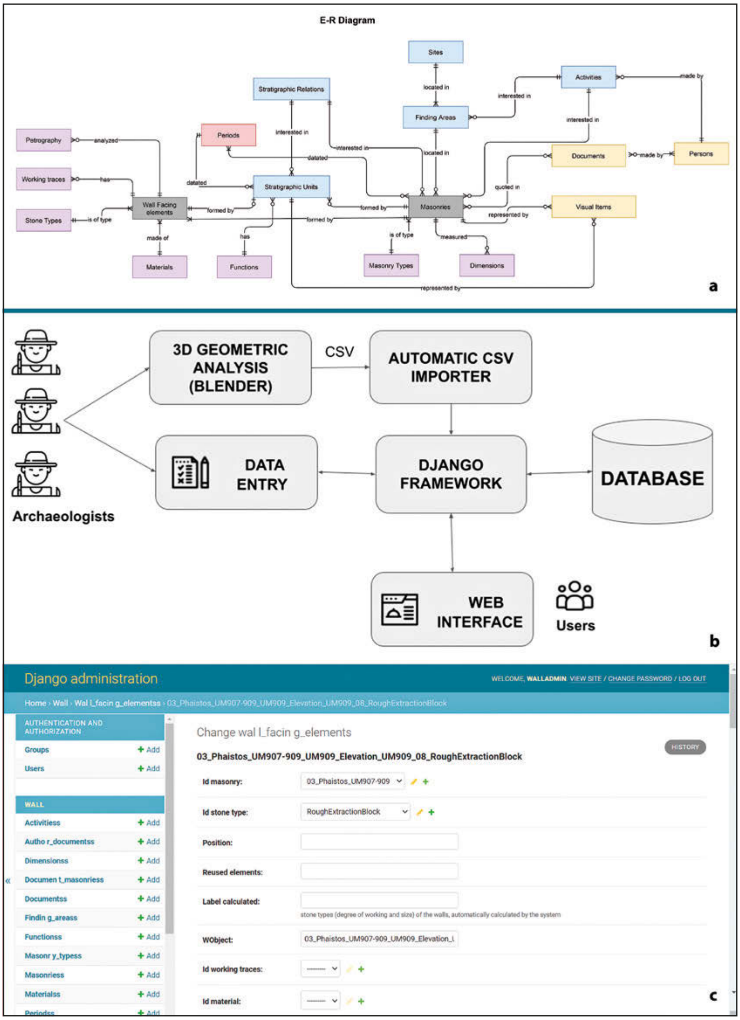

Fig. 3 – a) The Entity-Relationship Diagram with entities fulcrum of the system (gray) and entities related to localization (light blue), chronology (red), typology or characteristic (violet), documentation (yellow); b) the prototype architecture of the web application; c) the data entry model.

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

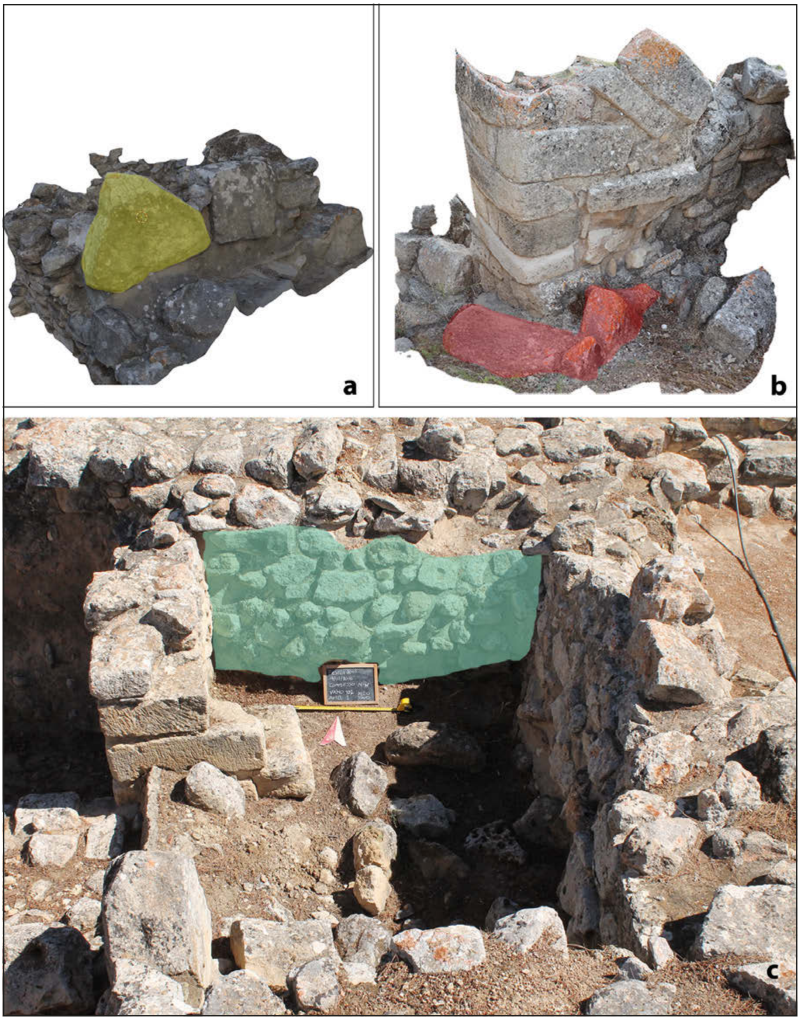

Fig. 4 – Guide fossils of the Geometric architecture at Phaistos: a) NE Sector, Room 103, Wall 907, triangular shaped stone used as a socle; b) Geometric Quarter, Room AA, polygonal slabs vertically arranged, modifying a previous wall line; c) NE Sector, Room 102L, lining wall.

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

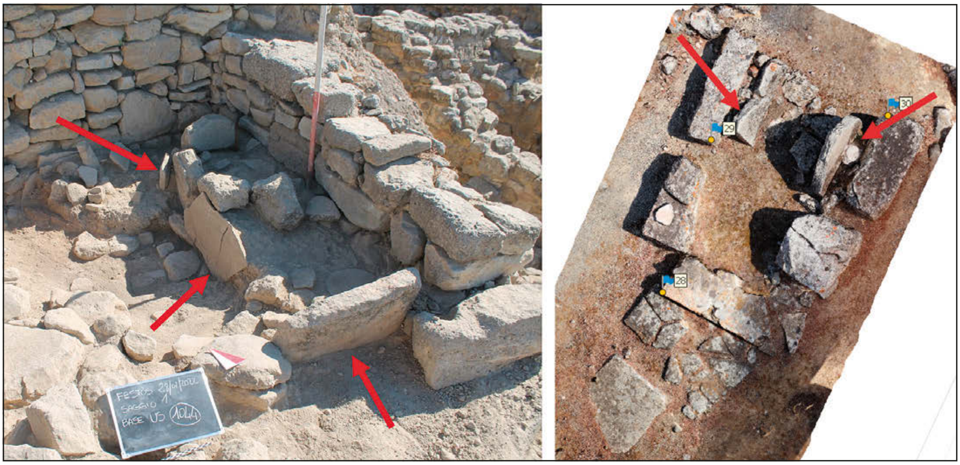

Fig. 5 – Polygonal slabs vertically arranged: a) Phaistos, Room NN; b) Ayia Triada, Altar.

LMIIIC period (12^{th}-early 11^{th} 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 (9^{th} century); the same consideration is valid for the rough coursing of the wall faces.

On the contrary, some examples of the 11^{th} and 10^{th} 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 (12^{th}-11^{th} century) more squared stones to a crisis of the regular masonry typology in the SM/PG (11^{th}-10^{th} century), until a new interest for regular wall facing in the 9^{th} 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.