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An automatic method for dimensional and shape characterization of pottery

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Abstract – **With the aim to improve the quality of the traditional archaeological approach and reduce costs for ceramic investigation, in this paper a computer-based method is proposed. A discrete geometric model of a pottery fragment is the starting input, from which a first distinction in axially and not-axially symmetric surfaces can be done. Geometrical and morphological features are then recognized. Only once that all these information are obtained, it is possible to proceed with the dimensional analysis. The method here proposed allows reducing the uncertainties of the traditional archaeological approach. The analysis carried on the test case here presented, proves that the automatic method presents repeatability and reproducibility that cannot be obtained even using the best application of the archaeological method. This method seems to be functional to other scopes such as for pottery classification and reconstruction of ancient ceramics.**

Keywords: **Computer methods in Archaeology, automatic feature recognition, surface segmentation, 3D archaeology.**

I. INTRODUCTION

The classification of archaeological objects, such as pottery, is based on shape, dimensions, decoration, technological elements, color and material. All of these features are recognized and analyzed by a skilled operator. Some of them, as decoration, technological elements and color, are studied by a visual analysis. The shape and dimensions characterization has largely been based on the graphical representation of findings [1]. The drawing of an object is compared to the others realized inside the same research and outside, meaning that pottery is grouped and recorded by a comparison with known classifications, allowing the attribution to specific ceramic typology. Traditional archaeological method follows several steps: orientation/inclination, diameter estimation, profile extraction, drawing of the fragments and additional measurements [2]. The traditional method presents the following four main limitations:

- the results depend on operator subjectivity, specialization, personal skills and professional experience, so that they are not reproducible and repeatable;
- since the method is time consuming, it is used to analyze only indicative fragments that have characteristic components such as a piece of rim, base, presence of grooves;

The direct consequences of the previously mentioned limits are, respectively:

- graphic documentation done by hand could raise errors possibility;
- the majority of fragments are not analyzed;
- only few representative fragments per type are drawn and published.

In order to overcome the above-mentioned limitations, an automatic methodology, performing algorithmically the previous procedure have to be implemented. This methodology needs the identification of the historical and artistic nature elements that can be recognized and codified based on the geometric properties of objects. At this purpose, during the past years, in the related literature, some automatic methods for findings classification are proposed [3-13]. All these methods analyze a geometric model of pottery coming from a 3D scanning. These methods require the whole pottery, none of them work with fragments, the most common archaeological finds. Furthermore, the shape descriptors used in literature, do not find obvious correspondence with those used by archaeologists to study the find. This is due to the necessity to recognize high-level information from a discrete model. This process is very complex to perform algorithmically, due to the low-level geometric information available: only the vertices coordinates of the geometrical grid representing the ceramic describe the geometric model.

Since some years, our research group deals with the development of a computer-based methodology that, automatically, performs classification and recording of findings, by detecting the typical features of the traditional archaeological method. In particular, in this paper, some results about segmentation of morphological and geometrical features and dimensional and shape characterization are proposed. The illustrated method, applied on a real case, shows better performances and lower uncertainties compared to the traditional approaches.

II. POTTERY FEATURES DEFINITIONS.

In this section, typical features considered in the traditional archaeological approach are exposed. These features will be then analyzed by the proposed automatic approach.

Typically, the archaeologists perform a first classification of pottery on the base of its overall features: *open* and *closed* shape. These classes can be labeled as structural for their functional implications, because the form adjust them to different uses. *Open shape* has a restriction of the vessel wall that helps in retaining the contents, especially if liquids, and makes potteries more useful for storage. The *closed shape* is suited for all purposes that may require the use of the hands inside the vessel and for display or drying of contents ([14]). However, potteries have different uses, for which they are not originally well suited by form. It can be said that the *closed shape* orifice has a diameter at the apical point smaller than the maximum vessel body diameter; on the opposite, the *open* one has the maximum vessel diameter at the orifice. In order to perform this classification, some morphological and dimensional features have to be recognized and evaluated. Generally, a fragment is a too small entity to retrieve all the necessary information to distinguish an *open shape* to a *closed* one.

At a more detailed level, some distinctive features must be recognized from the pottery shape. At this purpose, two kind of features can be retrieved: *geometrical* and *morphological*. The morphological ones are not axially symmetric parts connected with the external wall of the pottery; they are, for example, *handles* and *ribs*. On the other hand, *geometrical features* are related to the axially symmetric part and can be subdivided in different additional features, based on their specific geometric properties. At this purpose, based on experience of archeologists, four kind of features can be retrieved (figure 1):

- *external wall*;
- *internal wall*;
- *rim*;
- *base.*

The *external wall* is the external surface and a significant part of the pottery where, sometimes-different sub-features can be found: for example *torus* and *axially symmetric decorations*. The *external wall* may presents non-axially symmetric elements, such as bas-relief decorations, *handles* and *ribs* and graffiti.

The *internal wall* is not always a visible part and is generally unnoticed in pottery studies, unless it preserves decorations or significant traces. Anyway, it is an important feature to be recognised in order to identify some dimensional and geometrical properties (e.g. pottery's axis, wall thickness, etc.).

The *rim* is the upper part of the ceramic that generally corresponds to the opening of the pottery. It connects the *external wall* to the *internal* one. In order to identify univocally the *rim*, it is assumed to contain the upper extreme part of the pottery and the adjacent rounds.

The *base* is the bottom part of the pottery covering as a continuous surface from the lower extreme part to the axis.

The features and sub-features recognition process is more complex when the pottery is found in fragments. Nevertheless, the large number of ceramic materials discovered during excavation is fragmented. The study and classification of pottery often relies on sherds: starting from them, it is necessary to recreate the whole shape in order to interpret the original type, to which the fragment belongs.

The pottery's dimensions identification is an important phase that helps to recognize the previously described features.

A geometric approach to ceramic investigation involves primarily vessel proportion and contour. Proportion are express through a dimensional way, as ratios. The pottery shape is more difficult to describe and it can be done both by analysing the general characteristics of the silhouette and by comparing specific shapes with a taxonomy of geometric figures. The vessels silhouette can be segmented so that some characteristic points can be identified (figure 1):

- end points situated at base and rim (**A**, **B**);
- points of maximum/minimum diameter where the tangent is vertical (**M**);
- inflection points, where the curvature changes from convex to concave and vice versa (**P**);
- corner points where the direction of the tangent changes abruptly.

The fundamental importance of these points is reflected in the fact that some typical vessel dimensions are calculated from them. Based on these characteristic point and the associate dimensions, the base shape class can be identified.

The dimensional features are significant parameters that efficiently describe the objects. For example, if different potteries are characterized by similar morphological elements and therefore barely classifiable, information about dimensional differences can be helpful in achieving a more accurate classification ([15]).

Typically, *dimensional features* used by the archaeologists to drive the sherd classification are (figure 1):

- the thickness of the *rim* (t_{R1});
- the height of the *rim* (t_{R2});
- the diameter of the pottery at the apical point of the *rim* (φ_R);
- the maximum diameter (φ_M);
- the thickness in correspondence of the *base* (t_B);
- the maximum diameter of the *base* of the pottery (φ_B);

- sherd height (h_p);
- the thickness of the *wall* (t_w).

These *dimensional features* need the preliminary estimation of the axis of the pottery. The axis detection is somehow traditionally researched in archaeology, through identifying diameter in the drawing phase of the archaeological method. Since the quality of axis estimation has an effect on the quality of measurements executed on potteries, it is fundamental to use a repeatable and reproducible procedure for this identification. The traditional method, unfortunately, does not allow to accurately detecting axis, because several issues influence its quality. The axis is not a physical entity; it is an ideal geometric entity, which can be associated to a real object but not rigorously deduced. Even potteries produced by wheel can be slightly deformed, showing consequently that the section is not perfectly circular and concentric to each other. In addition to that, it must be taken in consideration that ceramic surfaces are often deteriorated by time and weathering.

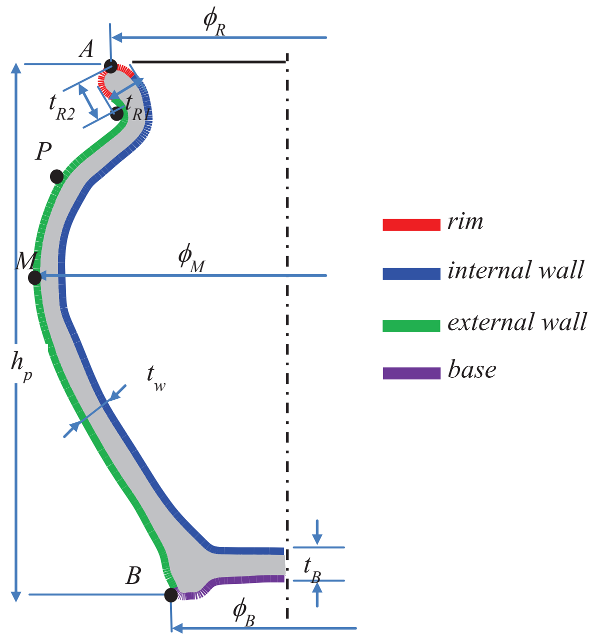

Fig. 1. Dimensional features and characteristic points

In addition to the above-mentioned features, the *fractured surface* can be identified. This is the feature that determines a relationship of the fragments with the others of the same vessel.

III. THE NEW METHOD

The aim of the computer-based method here proposed is to recognize pottery's features in accordance with the way archaeologists perform the conceptual categorization of ceramic. Therefore the traditional way of studying archaeological pottery needs to be translated in an automatic method. This means that features easily recognizable to an experienced operator could be not easily detected with an automatic approach and vice versa. However, reducing uncertainties could be a direct benefit coming from an automatic method, together with reproducibility and repeatability missing in traditional method.

The automatic method here proposed, starting from an acquired high point density model, algorithmically performs:

- *geometrical* and *morphological* sherd features segmentation and recognition,
- *dimensional feature* evaluation.

A. The new method for geometrical and morphological analyses of fragments

The sherd's geometric model has to be process to carry out a feature segmentation of its surface. A specific analysis is required to identify, in the *geometric features* previously mentioned (in the section II), those elements necessary to recognize the sub-categories associated to these features (as for example, the type of the *rim* or *base*). The segmentation and recognition phase of the method is briefly described in the flow chart in figure 2.

Identifying the axis is a preliminary operation, indispensable to perform a correct segmentation and recognition of geometrical and morphological sherd features. So that, it is fundamental to use a repeatable and reproducible procedure for this process, because the quality of axis estimation has an effect on the quality of measurements executed on potteries.

Performing an axis evaluation on archaeological fragments needs a process optimisation to reduce the coarse quality estimation. The axis identification process is more difficult to be performed when the axially symmetric features is just partially spanned, as it is the case of a fragment [16].

Starting from axially symmetric segmented surface, the recognition of *internal wall*, *external wall*, *rim* and *base* is obtained by an original and proper analysis of the differential geometrical properties of the mesh. With a different specific procedure processing information that can be obtained from a triangular mesh, the *non-axially symmetric surface* is segmented in *morphological features, fractured surface* and *chips*.

Based on the nature of the fractured surface and the other morphological and geometrical properties, the sherd can be classified as described in figure 3. In the same figure, each type of sherd is depicted by using the segmentation results.

More details concerning the features recognition phases can be find in [17].

B. The dimensional feature evaluation

The next step is devoted to the identification of the dimensional features of the sherd. This phase can be conducted once the geometrical and morphological features have been identified and segmented. The aim of this phase is the evaluation of the characteristic dimensions of the vessel, so that the measures can be considered repeatable and reproducible with low uncertainties. The implemented dimensional features, identifiable in any vessels, are shown in figure 1. These *dimensional features* are evaluated on a section of the pottery performed with a plane Π passing through the estimated axis of symmetry ($\boldsymbol{\alpha}$). By sectioning a real sherd with a sheaf of planes containing the axis $\boldsymbol{\alpha}$ (Π_{α}), profiles, different from each other, result (Figure 4). The corresponding value of each parameter is assumed as the modal value of the performed measures.

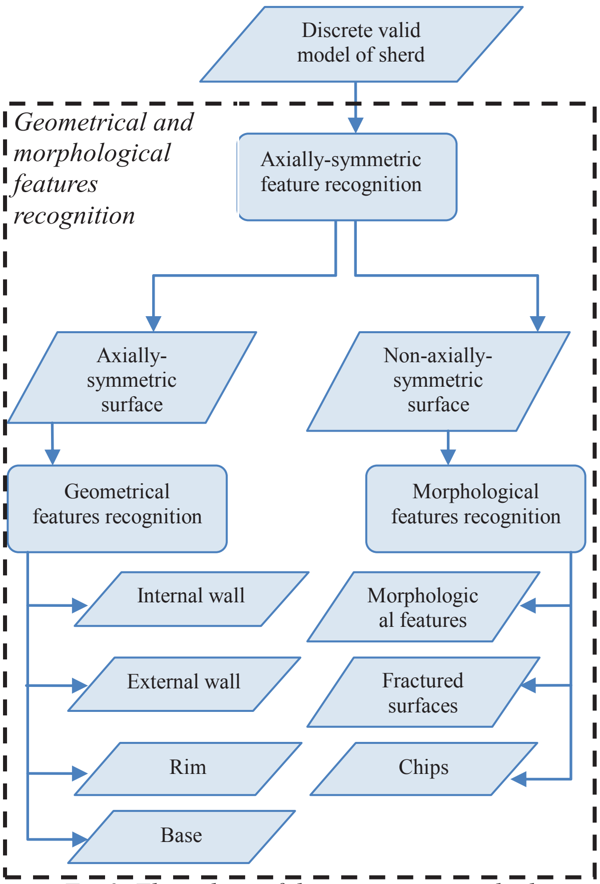

Fig.2. Flow-chart of the recognition method

IV. THE CASE STUDY

The proposed method is presented, and related results discussed, by analyzing a real test case. The test case used is an *open shape* fragment (figure 5) of a typical internal red-slip cookware (Pompeian Red Ware), produced from the third century B.C. to the second century A.C.

The discrete valid model of the sherd is obtained starting from the point acquisition of the data performed by a 3D laser scanner (FAROrEdge, 9 ft (2.7m), where single point repeatability goes from 0.024mm to 0.064mm. The average point spacing of the point cloud has been set to 0.2 mm. The point cloud processing for generating the geometric model is realized following the proceedings of reverse engineering [18]. In order to increase the method's exactness and prevented points clouds registration, a single scan of the fragment was made, by positioning the sherd on an edge. The figure 6 reports the results of automatic analysis of the test case.

In order to quantify the performances of the proposed method (*CB*: *computer-based* method), it is compared with the traditional one used in archaeology (*TD* method). These two methods are compared in terms of *intra-tester repeatability* and *inter-tester reproducibility*. Six archaeologists measured the sherd, both according to the traditional archaeological procedure and performing the 3D scanning of it.

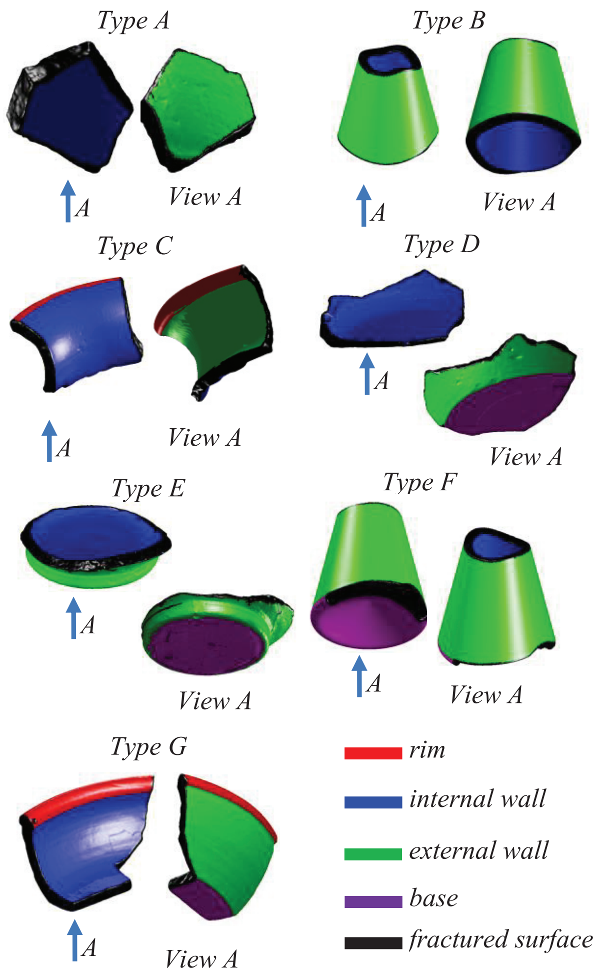

Fig.3. The new sherd classification

Measurements results have been concealed to all the operators. Each set of measures has been subjected to the Kolmogorov-Smirnov test to verify the normality of the data distribution. Six testers performing 20 measures of each parameter, in accordance with *TD* method, and 20 scans of the fragment (CB method) evaluated the Intra-tester repeatability (TRA). The *TRA* for both *TD* and *CB* methods is calculated, for each parameter, as the mean value of six standard deviations of the 20 measures performed by each tester. As regard the *repeatability* of the traditional method, figure 7 shows a comparison of 6 profiles drawn by one tester in terms of 2d representation (figure 7a) and 3d virtual vessel reconstruction (figure 7b). Table 1 illustrates values of *Intra-tester repeatability*, referred to the analyzed methods. Since the *CB* method calculates algorithmically parameters, its variability is mainly due to the axis estimation method that is a key aspect of the whole procedure. In any cases, the results presented in table 1 show that the *CB* method repeatability is always greater than that of the *TD*. *TRA* values become smaller, starting from a minimum of 70.83% for t_R to a maximum of 91.3% for ϕ_R.

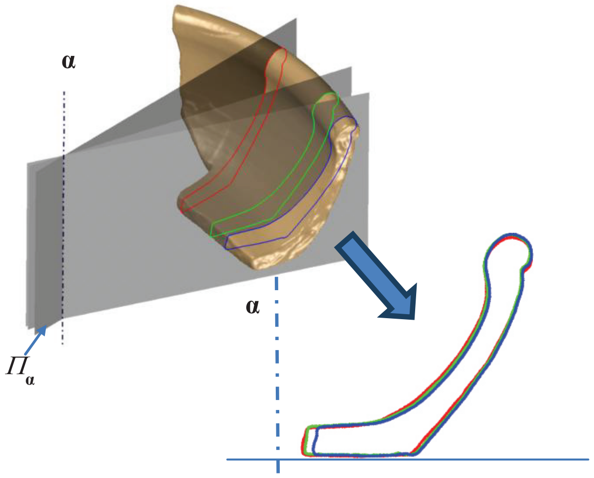

Fig.4. Intersection profiles

In order to evaluate the *Inter-tester reproducibility* (TER), each operator performs, as is set by methods procedure, three measures for each parameter. The *TER* is represented as the standard deviation of each mean values obtained by three measures. Table 2 shows the *inter-tester reproducibility*. In the case of the t_R and t_B parameters, the inter-tester reproducibility values, performed with the traditional method, are over 10%. By considering the *CB* method, the *TER/mean* is greater than 1% only for t_R. Globally, the *TER* results of the *CB* method is on average 10 times lower than those had with *TD*.

V. CONCLUSIONS

The proposed methodology is focused on the investigation of a wide amount of fragmented ceramic materials unearthed by excavations. The large quantity of pottery in ancient sites affects the study of this material since it is difficult and pricey to pursue. This method, based on the modern 3D geometric scanners, realized a high repeatable approach to ancient ceramic investigation. The traditional method for ceramic measurements has some deficiencies: it is poorly reproducible and repeatable, being affected by measurement uncertainties and lack of objective criteria to identify the dimensional feature. The test cases used to verify its capability evidence its effectiveness and possibility to improve the efficiency and objectivity of the archaeological work.

The method, based on feature recognition process, can be potentially the base for a new approach to pottery investigation and for pottery reconstruction from fragments. The segmentation of the potteries surface helps in classification purposes, (especially *rim*, *base* and *external wall*). These processes can lead on to an automatic classification method, which could be a solution of an extremely difficult and time-consuming task for conservators and archaeologists.

Fig.5. The test study

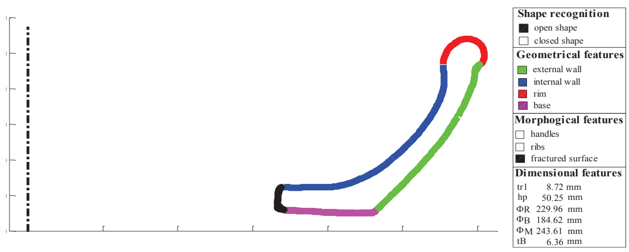

Fig.6. Results of the automatic analysis of the test case

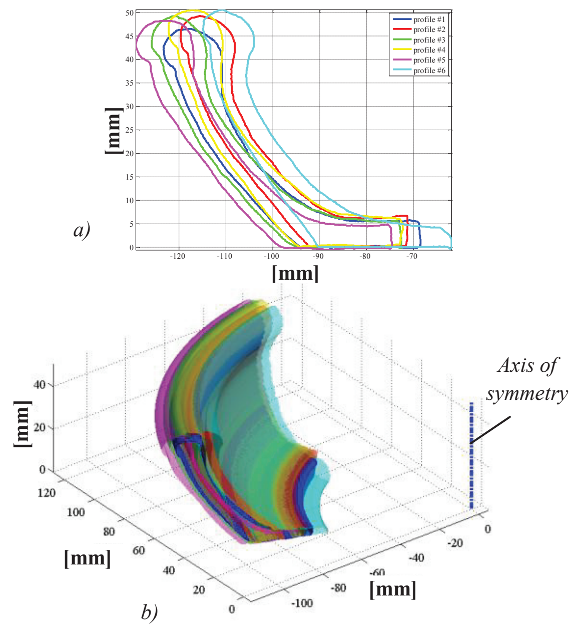

Fig. 7. Comparison of profiles drawn by one tester: a) 2d representation; b) 3d virtual vessel reconstruction

A further goal that the development of an automatic method (as the one here proposed) sets for itself is the ceramic type identification. The recognition of *rim* and *base*, together with the *external wall* segmentation in geometric features (based the type of point: *hyperbolic*, *parabolic*, *cylindrical* or *umbilical*), can be the base for a systematic classification of ceramics.

Moreover, the identification of the *fractured features* of the sherd gives the possibility to formulate in a new and easier way the puzzle associated to the reconstruction of vessels.

Table 1. Comparison of intra-tester repeatability.

parameter	*TRA*	
	TD	*CB*
t_R	0.48	0.14
h_p	0.91	0.12
φ_R	7.36	0.64
φ_B	7.28	0.47
t_B	0.41	0.07

Table 2. Comparison of the inter-tester reproducibility.

parameter	*TER*		*TER/mean [%]*	
	TD	*TD*	*TD*	*CB*
t_R	0.87	0.87	10.74%	2.28%
h_p	1.27	1.27	2.52%	0.4%
φ_R	5.70	5.70	2.46%	0.52%
φ_B	9.00	9.00	4.91%	0.38%
t_B	0.61	0.61	11.06%	0.92%

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