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# A new 3D information system for archeological pottery

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***Abstract:* The study of the immense patrimony of ceramic finds is still performed by the traditional manual archaeological approach. So that, the information of the shape and dimensions of the sherds have high uncertainties, are expensive and time consuming to be obtained. With the aim to overcome these limitations, for several years our research group has directed efforts to the development of an automatic computer-based method for the morphological and dimensional characterization of axially-symmetric shards. In this paper, the salient points of this method are reported, as well as the management system of all gathered information. The 3D information system is designed for its future use for pottery classification and reconstruction of ancient ceramics.**

## I. INTRODUCTION

Ceramics are the most common finds in archaeology and they contain fundamental information concerning history, economy and art of a site. Usually, the ceramic material are found, during archaeological surveys and excavations, in large amount and in the form of fragments.

The classification of ceramic material is based on shape, dimensions, decoration, technological elements, color and material. Nowadays, all of these features are recognized and analyzed by a skilled operator. Some of them, such as decoration, technological elements and color, are investigated by a visual analysis. The shape and dimensions characterization are largely based on the graphical representation of findings [1]. All this information are reported on printed catalogues; the operator, by a visual comparison with known classifications, assigns each analyzed found to a specific ceramic typology. Since ceramic materials are typically found in fragments, the previous operations are more complex to be performed. In a previous paper [2], the authors demonstrated as the traditional method for shape and dimensional characterization is not reproducible and repeatable. Furthermore, being the manual method time consuming, only indicative fragments that have characteristic components such as a piece of rim, base, presence of grooves are analyzed. Therefore, by using the traditional method, only a little part of fragments are associated to specific ceramics typology with great uncertainties.

With the aim to overcome the previous limits, our research group has codified some important knowledge elements, used by the archeologists to study the ceramic materials, in a new computer-based method [2]. Starting to a 3D discrete model of the fragments, the method, automatically, firstly segments the geometrical and morphological features and, then, evaluates the most important dimensional features. In [2] the authors demonstrated the new method is repeatable and reproducible.

In this paper, the information coming from [2], concerning the shape and dimensions, are expanded. This information is stored in a new structure based on a series of tables linked each other and files that can be displayed or queried by specifically designed search software. The proposed 3D information system is designed to solve another important problem in the archeological studies: assembly of fragments. This operation is performed manually by the operator with a trial and error strategy among wide sets of candidates. This procedure is complex both for fragments amount that have to be tested and for the possible lacks of pieces. The proposed 3D information system can be queried to cluster the fragments with similar information.

## II. THE PROPOSED METHODOLOGY TO AUTOMATICALLY EXTRACT INFORMATION

The storage and retrieval of archaeological data within computer databases is a basic component of modern archaeological research. Relational databases management system (RDBMS) are often used in archaeology to register and to document archaeological excavations, including information that describe the historical, stratigraphic, urban topographic context, with a focus on pottery. The ceramic databases try to standardize many repeated tasks encountered during the recording of archaeological and ceramic data in an efficient framework. They are a support for classification and interpretation, especially in post-excavation analyses.

There is not a common structure universally adopted for pottery database by researchers, but it is usually realized depending on the context and the archaeological site. Ceramic data are distributed in small databases in the individual analytical studies. The exchange of data among researchers is difficult because of the use of commonly diverse database formats. The records used are, however, the same for each study, because they take into consideration the most important feature of pottery. The voices outlined in database are quantity (number of sherds), origin, class, shape, typology, morphological features (rim, base, wall, handle) decoration, production, chronology, bibliography.

By analyzing the published databases, relative to the shape and morphology of finds, it results they report digitization of out-of-print fascicules ([4], http://www.beazley.ox.ac.uk/pottery/default.htm) or information performed by skilled operators [5]. The Pottery Informatics Query Database (PIQD) [3] is the only exception. In this case, the morphology of the ceramic vessel (coming from both 2D scans of illustrated ceramics profile and 3D acquisitions) is converted only in measurements of radii, tangent and curvature of its representative profile as a function of arc-length.

In order to overcome these, a new system to manage the following 3D information detectable by a fragment is proposed:

- Presence of morphological features;
- Fragments shape type;
- Typical dimensional features;
- Thickness distribution;
- 2d vessel profile.

The implementation of the proposed method requires the estimation at each vertex of the mesh of geometrical differential properties, such as normal *(medial quadric method* [3]) and principal curvatures (the *5-coefficients paraboloid fitting method* [8]).

Under the hypothesis the find is ideally axially-symmetric, the axis identification is a preliminary process that is necessary for each further analysis. In order to identify the axis **α** of the sherd, an original method, based on the *circle and line fitting approach* [9], is applied to the *widest convex* and *concave* patches of the fragment to be analyzed.

### A. Presence of morphological features

In what follows, morphological features are those elements deviating from an axially symmetric geometry. Typical morphological features are handles, lips, ribs and bas-relief decorations and graffiti. Typical handles are the only morphological features, which are distinct from the rest of the sherd. For this typical characteristic, handles are recognised separately with a specific method (figure 1). Known the axis **α**, the pottery/sherd is sliced with planes perpendicular to **α** (figure 1a); the handles are recognised (figure 1b) by segmenting the distinct regions from the principal central one.

The other morphological features of the find are segmented by analyzing at each mesh points the SHI index [12] (figure 2 a) and the minimum distance ($d_i$) between the normal line and **α** (figure 2 b). The 3D geometric model is segmented in axially-symmetric (figure 2 c) and non morphological features (figure 2 d) by applying specific threshold values to SHI and $d_i$.

### B. Features segmentation and fragments shape type classification

Starting from the 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 [13]. At the end of this phase, the sherd is classified on the base of seven categories reported in the figure 3, where:

- *Nep* is the number of recognised *extremal parts*;
- *Nfs* is the number of recognised *fractured surfaces*;
- *Cas* is the completeness of the azimuthal span;
- *g* is a topological invariant identifying the number of holes through the object;
- *g’* gives the maximum number of holes of the fractured surface.

More details and the recognition rules of these parameters are reported in [13].

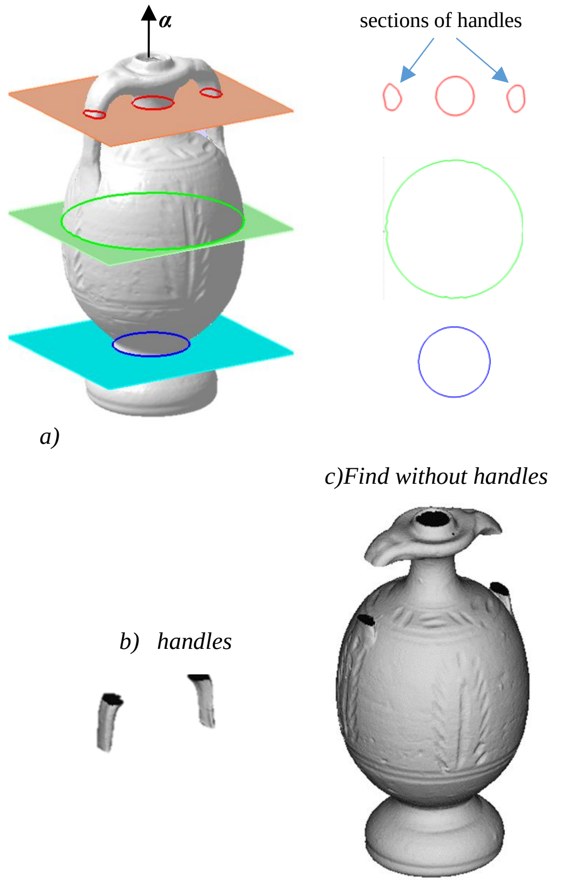



Fig. 1. Handles recognition

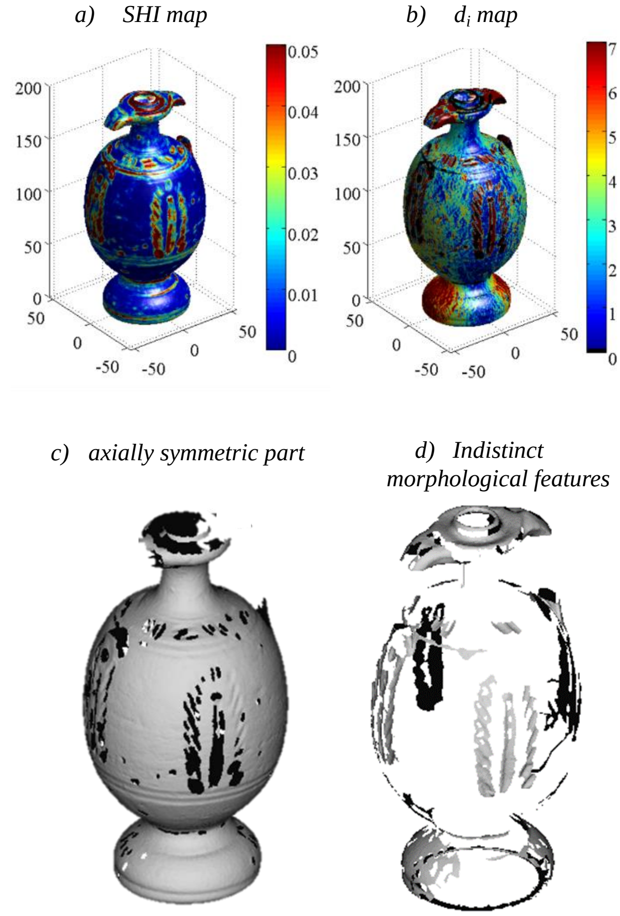



Fig. 2. Axially-symmetric feature segmentation

## C. Typical dimensional features

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 ([10], [11]).

Typically, *dimensional features* used by the archaeologists to drive the sherd classification are (figure 4):

- 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* ($\varphi_R$);
- the maximum diameter of convex part ($\varphi_M$);
- the minimum diameter of a concave surface ($\varphi_N$);
- the thickness in correspondence of the *base* ($t_B$);
- the maximum diameter of the *base* of the pottery ($\varphi_B$);
- sherd height ($h_p$);
- the thickness of the *wall* ($t_w$);

Since there could be more than one concave or convex features, there could be one $\varphi_{Mi}$ and $\varphi_{Ni}$. In some cases, a convex or concave sub features could not present a characteristic diameter, such as $\varphi_M$ or $\varphi_N$.

In order to automatically evaluate the dimensional features previously listed, firstly, the representative sherd profile $\rho=f(z)$ have to be evaluated. The sherd is aligned so that the axis $\boldsymbol{\alpha}$ coincides to the $\mathbf{z}$ axis. In the plane $\rho$ – z, at each $z_i$ value, the corresponding $\rho_i$ is evaluated as the radius of the circle approximating the points $\Gamma_i = \mathcal{M} \cap \Pi_i$ ($\mathcal{M}$ being the maniforld mesh of the axially-symmetric part of the find ad $\Pi_i$ being the horizontal plane passing through $z_i$) and centered on $\boldsymbol{\alpha}$. In order to neglect the noise in the further processes, the profile is smoothed. The smoothing, at each couple ($z_i$, $\rho_i$) is performed substituting it with the corresponding values taken from the parabola approximating neighborhood of ($z_i$, $\rho_i$) with a defined width.

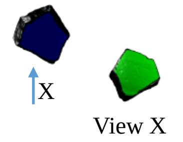
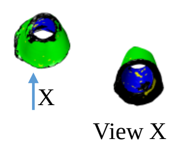
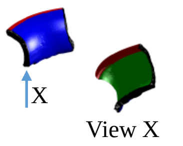
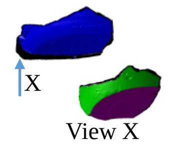
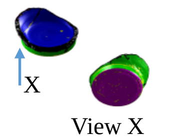
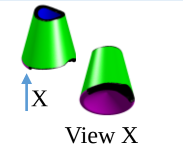
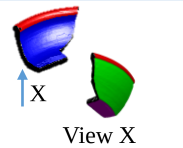
| *Type* | *Features* | *Parameters* | *Rendering* |
|---|---|---|---|
| A | Internal wall;<br>External wall | *Nep* 0<br>*Nfs* 1<br>*Cas* N<br>*g* 0<br>*g'* 1 |  |
| B | Internal wall;<br>External wall | *Nep* 0<br>*Nfs* 2<br>*Cas* Y<br>*g* 1<br>*g'* 1,1 |  |
| C | Rim<br>Internal wall;<br>External wall | *Nep* 1<br>*Nfs* 1<br>*Cas* N<br>*g* 0<br>*g'* 0 |  |
| D | Base<br>Internal wall;<br>External wall | *Nep* 1<br>*Nfs* 1<br>*Cas* N<br>*g* 0<br>*g'* 1 |  |
| E | Base<br>Internal wall;<br>External wall | *Nep* 1<br>*Nfs* 1<br>*Cas* Y<br>*g* 0<br>*g'* 1 |  |
| F | Base<br>Internal wall;<br>External wall | *Nep* 1<br>*Nfs* 2<br>*Cas* N<br>*g* 0<br>*g'* 1,0 |  |
| G | Rim<br>Base<br>Internal wall;<br>External wall | *Nep* 2<br>*Nfs* 1<br>*Cas* N<br>*g* 0<br>*g'* 0 |  |

Fig. 3. *Sherd type recognised*

Once the profile is smoothed, its dimensional features are calculated.

The thickness is evaluated on the profile for each point corresponding to points of the *internal wall* as the minimum distance respect to the faced points.

In order to characterize dimensionally the external part of the profile the *shape index* $s_i$ [14] is evaluated at each point:

$$s_i = -\frac{2}{\pi} arctang \frac{H_i}{\sqrt{H_i^2 - K_i}}$$

Where

$$H_i = \left(\frac{1}{\rho_i} + k_{p,i}\right) \Big/ 2$$

$$K_i = \left(\frac{1}{\rho_i} \cdot k_{p,i}\right)$$

$k_{p,i}$ is the profile curvature in ($z_i$, $\rho_i$). The segmentation of the profile is performed according to the classification reported in the table1.

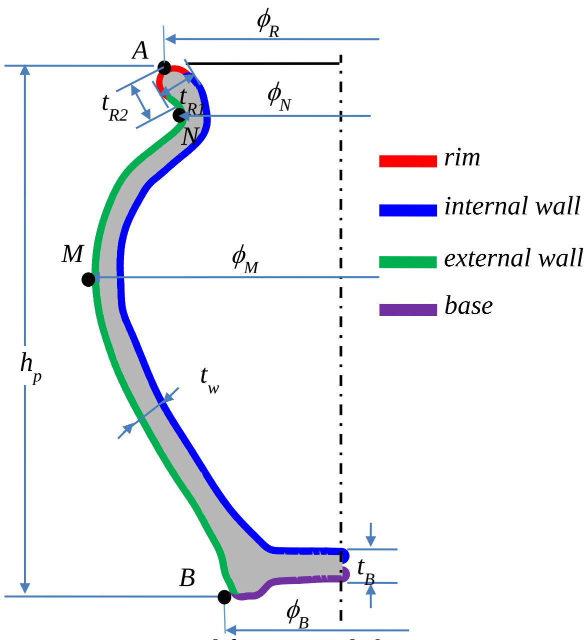



Fig. 4. Dimensional features and characteristic points

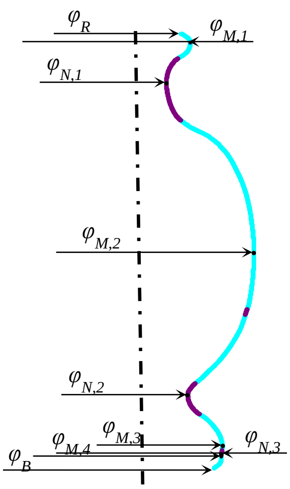
*Table 1. Type point classification based on index s.*

| ***s range*** | ***Type point*** |
|---|---|
| s<=-1+Δs | concave umbilical (uc) |
| -1+Δs <s≤-0.5-Δs | concave elliptical (ec) |
| -0.5-Δs <s≤-0.5+Δs | concave parabolic (pc) |
| -0.5+Δs <s≤-Δs | concave hyperbolic (hc) |
| -Δs <s≤Δs | hyperbolic saddle (hs) |
| Δs <s≤0.5-Δs | convex hyperbolic (hx) |
| 0.5-Δs <s≤0.5+Δs | convex parabolic (px) |
| 0.5+Δs <s≤1-Δs | convex elliptical (ex) |
| s>1-Δs | convex umbilical (ux) |

For each segmented portion of the profile, the following dimensions are evaluated:

- $d_{in}$: the initial diameter of the portion;
- $d_{fin}$: the final diameter of the portion;
- $d_{rep}$: is the minimum (maximum) diameter for a concave (convex) tract.

In the figure 5 is reported the results of the dimensional characterization of the external part of the profile of the amphora reported in the figure 1.




| *diameter* | *CBM* |
|---|---|
| $\varphi_R$ | 35.7 |
| $\varphi_{M,1}$ | 43.9 |
| $\varphi_{N,1}$ | 22.5 |
| $\varphi_{M,2}$ | 100.5 |
| $\varphi_{N,2}$ | 41.4 |
| $\varphi_{M,3}$ | 72.2 |
| $\varphi_{N,3}$ | 68.3 |
| $\varphi_{M,4}$ | 71.5 |
| $\varphi_B$ | 64.7 |

Fig.5. Dimensional characterization of amphora

## III. THE STRUCTURE OF THE PROPOSED 3D INFORMATION SYSTEM

The proposed architecture is typical of a relational database management system: it is based on a series of tables linked to each other and to files. In the figure 6, the structure of the whole 3d information system and of tables and files that constitute are summarized.

## IV. IMPLEMENTATION OF THE PROPOSED 3D INFORMATION SYSTEM

The whole procedure to automatically evaluating the dimensional features of sherd is coded in MATLAB ®. In a previous paper [2], authors demonstrated the repeatability and reproducibility in the evaluation of some dimensional features here considered.

In order to verify the performances of the proposed 3D information system, 168 sherds are processed. These are ancient Roman archaeological sherds, excavated on the Alba Fucens site (Italy) (Fig. 7). The sherds are of various dimensions and their surfaces are weathered and eroded. All the fragments were scanned by a 3D laser scanner (FARO Edge, 9 ft (2.7m)), where the single point repeatability was less than 0.064 mm. The average point spacing of the point cloud was set to 0.15 mm. The point cloud processing for generating the final geometric model was realized using commercial software (Geomagic ®).

With the aim to simplify the management of the 3D information system, a user interface is coded in MatLAB®. In figure 8 the results in the processing of one of 168 sherds are summarised in the implemented GUI.

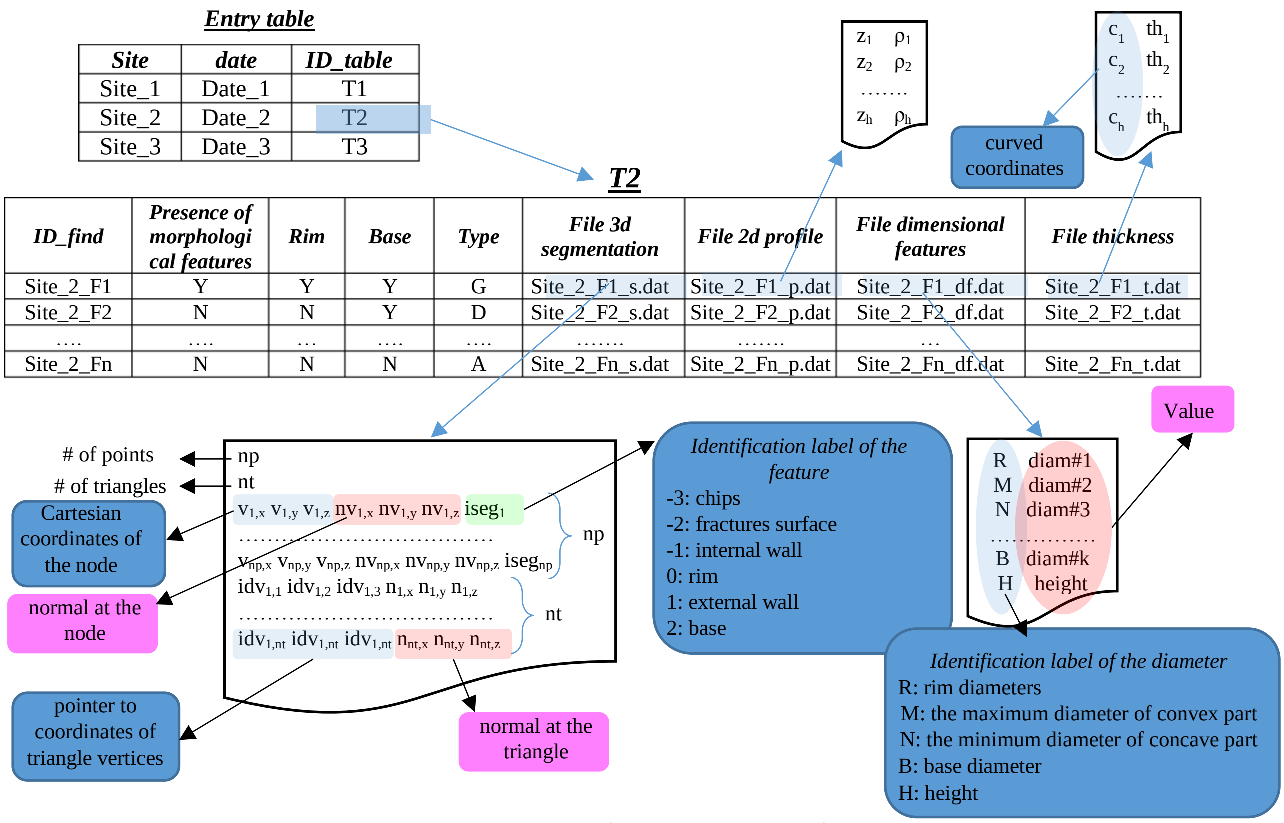



Fig.6. The structure of the proposed 3d information system


Fig. 7. 168 Roman archaeological sherds excavated on the Alba Fucens site (Italy)

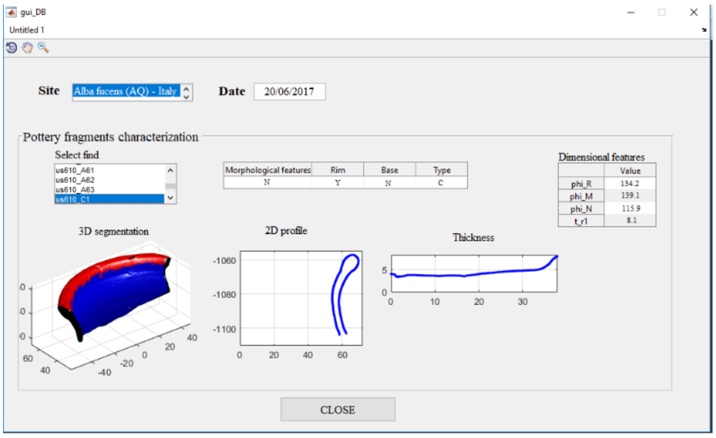



Fig. 8.The GUI of the proposed 3D information system

## V. CONCLUSIONS

Until now, the study and classification of the large amount of pottery in ancient sites are performed by the manual traditional method. This method has some deficiencies:

- it is poorly reproducible and repeatable, being affected by measurement uncertainties and lack of objective criteria to identify the dimensional feature.
- it is time consuming and, since required a skilled operator, is expensive.

As direct consequence, typically, uncertain information is available on the shape and morphology of only the considered significant part of the sherds found in a site.

At the purpose to overcome these limitations, for several years authors are developing an automatic computer-based method for the morphological and dimensional characterization of axially-symmetric shards. The method, starting from a 3D discrete model of the find, first segments the axially and not-axially symmetric surfaces, then recognizes the geometrical and morphological features. Finally, it calculates the dimensional features. In this paper, the salient points of this method are reported, as well as the management system of all gathered information. The main functionalities of the 3D information system are tested in storage of data obtained by the analysis of 168 ancient Roman archaeological sherds, excavated on the Alba Fucens site (Italy).

Future efforts will be addressed to the extension of information, such as the colour characterization of the sherd. Furthermore, specifically designed queries will be implemented to support a new automatic procedure for the pottery classification and reconstruction of ancient ceramics.

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