Using Reverse Engineering In Archaeology: Ceramic Pottery Reconstruction

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Abstract:
The present paper presents a model for using CAD software and reverse engineering methods for the reconstruction of ceramic vessels, as part of the larger field of digital archeology. The case study focuses on the reconstruction of a specific Dacian pottery, namely the "chiup", used for storing food ad liquids, and the proposed reconstruction method is a graphical one.

Keywords: *CAD, reverse engineering, digital archeology, ceramic pottery, reconstruction*

1. Introduction

In the UNESCO vision, "cultural heritage is our legacy from the past, what we live with today, and what we pass on to future generations", and in our opinion digital archeology is a way to contribute to this desiderate. Knowledge and understanding of history is an important part of the education of any modern citizen and it has been so even since ancient times. It is believed that the lessons of the past should be passed on to the new generations in order to avoid making the same mistakes and to increase the speed of progress. Engineers can help to save and reconstruct the past with specifics tools and techniques from their domain used in archeology and in connected domains, in an interdisciplinary approach.

Historians have been preoccupied for a long time with the reconstruction of historical artifacts, events or figures, a few of the methods used in this direction are presented in Table 1.

Table 1. Reconstruction methods used by historians

Studied object	***Reconstruction method***
Partial artifacts	Laboratory reconstruction with specific methods and tools
Lost artifacts	Drawings, 3D models based on existing information
Events	Reenactments, drawings, computer simulations
Figures	Drawings, 3D models, animations
Media/Information	Interpretation of specialists
Society/Relationships	Reenactments of social situations
Architecture	Renovation of buildings, monuments, etc.

Fig.1. Dolium, left (Museo Archeologico Nazionale della Sibaritide) and Chiup, right (National History Museum of Transylvania Cluj-Napoca)

In this paper there are presented an algorithm and an experimental method for ceramic pottery reconstruction (starting with fragments) based on reverse engineering techniques and CAD modeling. The paper focuses on a special pottery type: the chiup from the Dacian civilization (Romanian civilization ancestor).

The Dacian chiup imitates the Greek Dolia or Pythos vessels, retaining most of their features with small modifications [1], [2]. The chiup is an arched, oval shaped vessel, with its maximum diameter in the superior part of the body, used for grain storage.

Some specimens have a 2 m diameter and in order to be filled and used properly had to be buried in the ground or hold on special support, due to the instability resulted from its shape. In proper conditions a great quantity could be stocked, but the degree of instability proportionally increased with the amount of filled grain.

These types of vessels were obtained using the wheel, with a special technique necessary for managing the high weight of the raw material, ceramics. The vessels' walls were shaped on segments being added successively as the previous one dried. The joints were made perfectly, without any visible marks, and the bottom part was attached to the corresponding walls at the final stage of the process.

Regarding the dimensions, the vessels diameters move mainly on a scale of 0.50 m to 1.50 m, but there also exist samples which reach a maximum of 2 m. It is a remarkable fact that among the several elements of these vessels there can be identified a clear correlation. It can almost be stated that their development followed some kind of standardization [1], [2].

2. Methodology and set-up

In the authors' opinion, the results of digital archeology are an electronic file (or application) with a complete description of an historical artifact (3D and other information). In this sense, restoration and digitization should envision at least two possible uses of the virtual artifact:

- **virtual museums** – digitization is focused on the aspect of the 3D artifact which should closely resemble the real one;
- **research** – digitization is focused on the shape and material of the artifact, so that it could be used for comparison with other similar vessels or vessel fragments, from the same or from other studied cultures.

Performing artifact reconstruction should be a structured process aimed at achieving the most accurate solution, i.e. the reconstructed product reproduces faithfully the characteristics of the original. Also, the reconstruction effort should be a team one, with at least the following important functions being represented:

- **historians and archaeologists**: provide essential knowledge about manipulation permissions and restrictions, ensure the historical accuracy of the resulting reconstruction, as well as to put forward solid hypotheses about missing parts based on knowledge of the given historical age;
- **reverse engineering / CAD specialist**: designs and implements the technical solutions for digitizing the partial existing artifact and for "filling in" the missing pieces;
- **artists / art historians**: artists that are specialized in certain time periods can bring the aesthetic perspective in correctly defining the missing parts of different artifacts;
- **IT specialist**: develop virtual artifact (3D model + additional information) for electronic libraries or virtual museums.

The authors of this paper propose the following methodology that the interdisciplinary team should follow in order to obtain a 3D model (including reconstructed model) for a ceramic pottery (see Table 2).

Table 2. Step for the reconstruction of ceramic artifacts

No	Operation	Set-up and observations
1	**Artifact analysis** – determining the need for reconstruction, time period characteristics, physical characteristics, manipulation constraints, legal issues etc.	Assembling the reconstruction team and regular team meetings for establishing a common road map and time frame.
2	Establishment of the best **reverse engineering techniques** (scanning device, software, environmental conditions etc.)	Available reverse engineering techniques and equipment compared to reconstruction costs and accuracy requirements. It is possible that a combination of scanning techniques is necessary (regular laser scanning, texture laser scanning etc.)
3	Establishment of the 3D **scanning strategy**	Scanning device constraints should be observed and the best approach should be determined.
4	Defining and building the necessary **protection measures**	Fixtures, supports, other means of protection.
5	**Digitization of the artifact fragment** (3D scanning and creation of the 3D model)	3D scanning device, scanning techniques, scanning program, CAD software able to process clouds of points and to communicate with the scanning device.
6	Implementing the choosing **reconstruction solution**	Method and geometrical algorithm for reconstruction, detailing and finishing of the CAD model in the reconstructed state.
7	**Digital artifact**	Additional information will be added to the 3D model: set-up visualization mode and alternative, protect the digital artifact-copyright, etc.

3. Case Study

In the following we will present a case study of the proposed methodology for reconstruction in the digital environment of the chiup pottery type, used by the Dacian civilization around the 1st century BCE and 1st century CE

1.1. Artifact analysis

Archeologists have discovered that these types of vessels are mostly found around the capital of the kingdom, Sarmizegetusa Regia [1], [2]. One of the explanations could be provided by the capital region's geography, a mountainous region, where the usual way to store grain, that of digging holes and reinforce them with clay, like it used to be practiced in the plain areas, could not be applied, so they used pottery vessels instead [1], [2]. Regarding the discovery places, the vessels were discovered in houses, as well as inside the fortress. The presence of a large number of vessels inside the fortress can be considered natural, as the quantity of water and grain needed was higher than for a usual house.

Considering the vessels' dimensions, the physical reconstruction requires a high amount of effort especially if the pieces found are small regarding their size. The existing fragments reconstitute approximately 1/4 of the entire chiup.

There are some particularities of these vessels that facilitate the reconstruction using a graphical method:

- the archaeologists have realized that these vessels are sort of standardized, therefore establishing a series of relations between the proportions of certain parts of the vessel such as: that between the vessel's height and the diameter of the entrance is between 1/2 and 1/4, between the height and the maximum diameter the ratio is between 2/1 and 3/2, and between the low end diameter and the height it is between 1/4 and 1/9 [1], [2].

- another particularity of these vessels is the fact that they are modestly decorated, which makes the reconstruction process difficult, because it does not give the restaurateur important indications about the actual position of the pieces; the decoration elements were placed on the upper side due to the fact that the lower side was in the ground [1], [2].
- the vessels were created using the potter's wheel, which means they have a well-defined symmetry axis.

1.2. Choosing the reverse engineering technique

Even if the vessel has been baked in special ovens, the use of contact scanning can be harmfull for the remaining fragments. Laser scanning will the method be used for digitization, by using a precise laser scanner (Kreon Zephyr) and a portable CMM for obtaining the research model, and a hand-held texture laser scanner (VIUScan from Creaform) for obtaining the model destined for a virtual exhibition.

1.3. Scanning strategy

When using the portable CMM + laser scanner solution, the fixing of the part must expose its surface within the working zone of the CMM. When using the VIUScan texture scanner, which is a self-positioning scanner, positioning targets must be applied on the surface of the fragments, but in order to avoid this, the work team has manufactured the necessary target grid by using transparent foils cut out in the shape of the actual fragments.

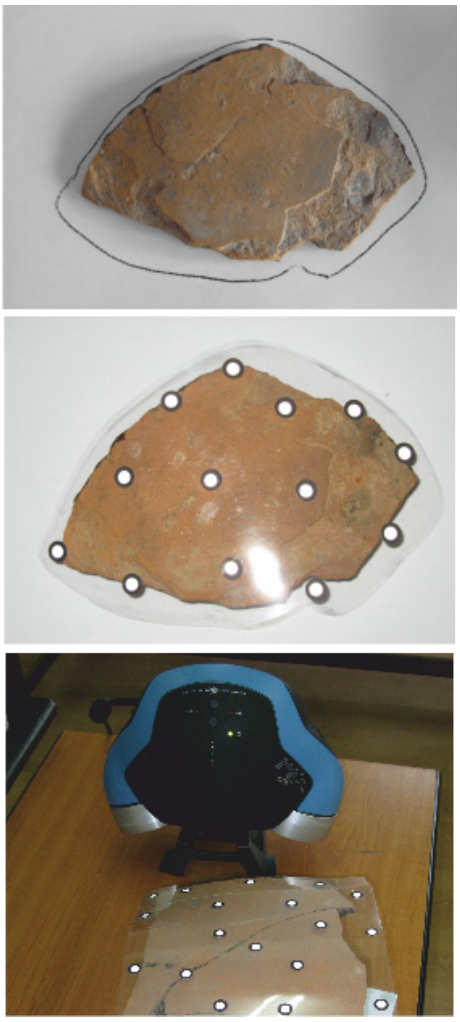

Fig. 2. Target grid and ViuScan

1.4. Protection measures

The following issues have been considered: the object was manipulated with gloves, for fixing fragments plasticine was used, a material softer than the artifact, with no additional help (clamps, glues or other means).

1.5. Digitization of the fragments

The digitization of the vessel's pieces is done using two laser scanning devices: Kreon Zephyr and Creaform ViuScan. In this phase, a preliminary grouping of the fragments can be done, for the fragments whose position in the vessel structure is obvious. The digitization step ends once the surface or the virtual solid object is generated and can include a step in which the textures are applied [8], [9]. Using the mentioned laser scanning technique, the resulted cloud point (Fig. 3a) has been transformed into a surface (Fig. 3b) on which later on the texture has been applied (Fig. 3c) from the original fragment (Fig. 3e) in case of scaning with Kreon Zephyr, and the fragment scaned using ViuScan with the scaned texture (Fig. 3d).

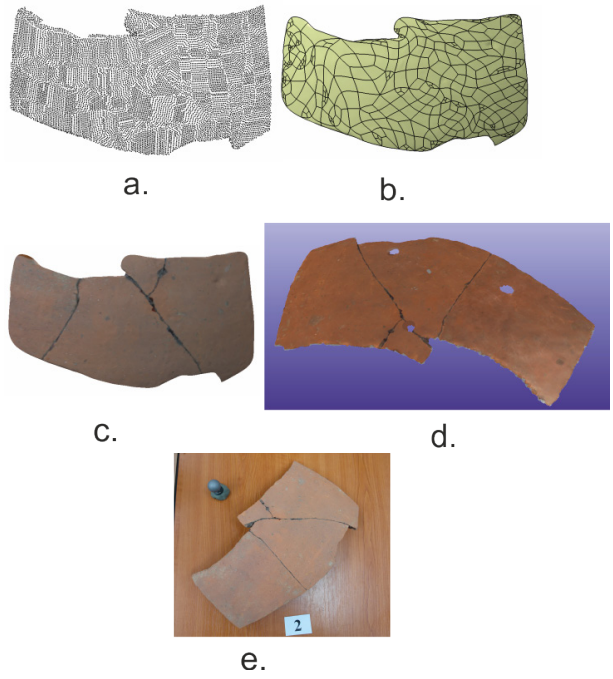

Fig. 3. Digitized vessel fragment: a-point cloud; b-surface;, c-textured surface; d-fragment scanned with ViuScan; e-fragment discovered at Gradistea de Munte

1.6. Reconstruction solution

In the chiup case, the reconstruction method is based on rebuilding the profile of the vessel, which is used to generate the entire artifact through an operation that implies rotating the rebuilt profile around the theoretical axis of the vessel [3], [4], [6].

After obtaining the surface for each piece, a series of transversal and longitudinal curves can be determined, this will be used at the next step for grouping the fragments.

In figure 4 is represented a fragment with the adjacent curves obtained from the intersection of the surface with the perpendicular plains on the theoretical axis of the vessel, and with the planes that contain this axis. For each of the fragments, there are generated circles with

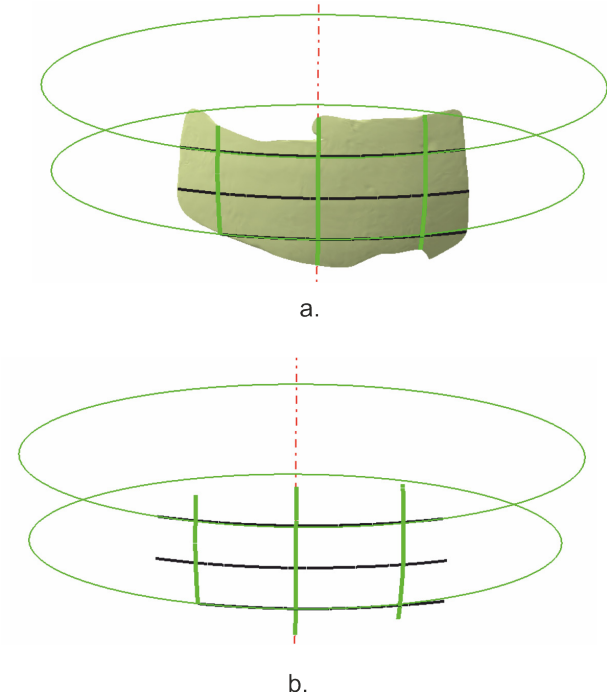

Fig. 4. Generation of transversal and longitudinal curves

a maximum and a minimum diameter which will be used in the next phase when grouping the fragments on diameter intervals.

The next step in the reconstruction of the chiup is to group the fragments, in this case six segmenting intervals have been established. For each interval, the inferior and superior limits were set.

The boundary curves which separate the surfaces are generated for each fragment of the vessel [7]. These are used later on for matching of the components of a certain group of pieces.

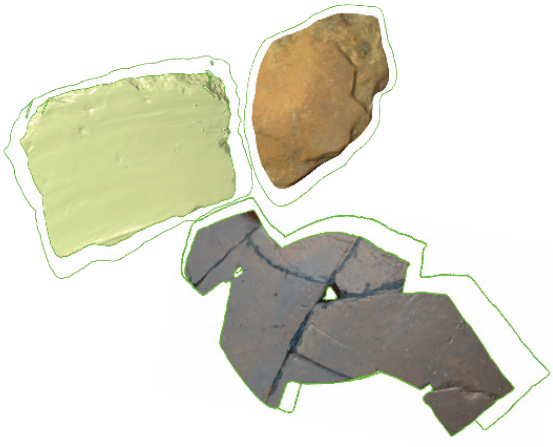

Fig. 5. Matching fragments using boundary curves

Generation of the vessel's profile has to be performed as much as possible in the most complete section. The profile can be generated using more pieces if it is necessary and then, through a projection into a plane, the obtained profiles can be joined in order to achieve the complete profile. Using a simple geometrical operation (revolve) the entire vessel is generated.

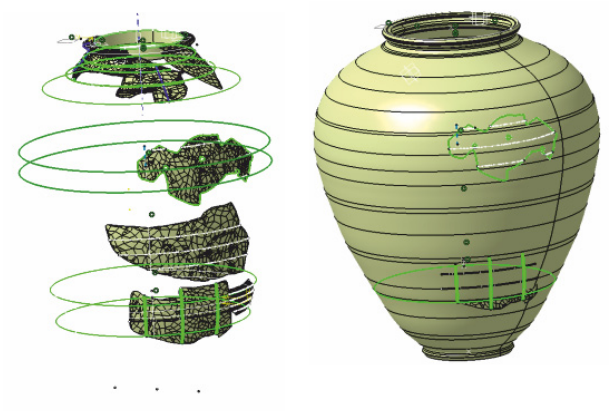

Fig. 6. Intermediary stage (left) and final reconstruction

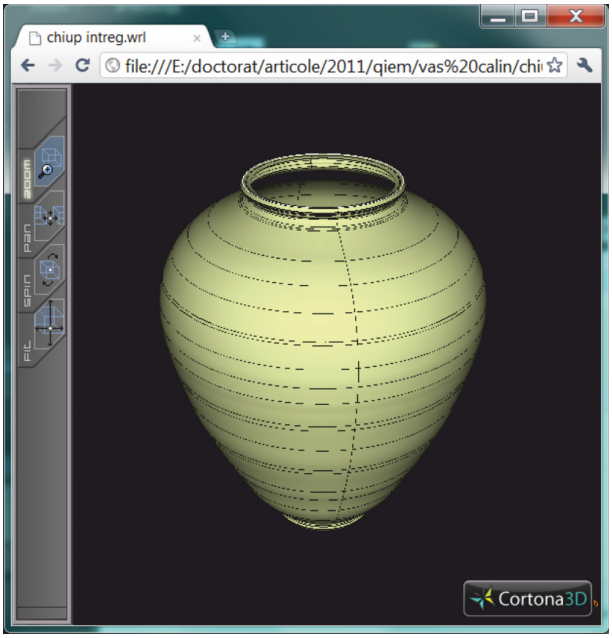

Fig.7. Digital artifact in web browser

1.7. Digital artifact

For visualizing and manipulating the virtual artifact, the wrl format is used, containing in a single file both the 3D model and additional information (e.g. short description, links etc.). This format can be accessed with the help of a web browser and it can be easily integrated into a virtual museum.

3. Conclusion

The reconstruction of ancient ceramic pottery is a subject of interest approached by many re-searchers [3], [4], [5], [10], [11] and [12] in some cases attempting an automated reconstitution by using special algorithms from the field of image processing. A graphical reconstruction (based on the geometry of the fragments) involves a high work load, but in the situation described in this paper, reconstruction of a chiup, it may be the only method that leads to a satisfactory result, due to the particularities of these vessels, such as the absence of decorations, which makes image processing reconstruction nearly impossible.

An interdisciplinary team is necessary in order to carry out such a project, and there exist a series of limitations which, in some conditions, cannot be overcome. For example, when only smaller fragments exist, it may be

difficult to distinguish the symmetry axis of the vessel, making it impossible to establish the position of the fragment. Yet this problem may occur in any re-construction method, even in the conventional one when the vessel is complete.

Using reverse engineering as an instrument for archaeology may lead to obtaining virtual artifacts that can be used for experimental research, if their digitization is precise, as well as for virtual exhibitions, if the artifact is digitized together with its texture.

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