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RECONSTUTION OF CERAMIC VESSELS FROM THE FAMILY OF CHIUPS

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Abstract: *The paper proposes a method for the reconstitution of Dacian ceramic vessels, named "chiup". These were used to store grain and were among the most widespread vessels for supply of the Dacian world. Due to their large dimensions the reconstitution process raises several difficulties from both technical and geometrical point of view. The digital reconstruction method presented in the paper is based on laser scanning and also on special modeling techniques. The method uses only geometrical operations and proposes a manual reconstitution of the entire vessel, without involving automatic matching.*
Key Words*: ceramic vessels, chiups family*

1. INTRODUCTION

Hand-made ceramic objects were created by our ancestors and were used in daily activities as well as for religious purposes. Ceramics is the material with the most prevalent appearance in archeological findings, in most cases the vessels being fragmented and incomplete. Employing these objects in day by day activities has a negative effect on them regarding wearing.
Different upcoming accidents may lead to partial or total damages, making the objects useless, although „Gods-acts" such as natural catastrophes or wars also happen., and preserving ceramics for the future generations.
If in the case of planar objects reconstitution is reduced to solving a 2D puzzle, ceramic vessels transform the problem in a 3D puzzle, which just as the 2D, has only one correct solution.
The Chiup is an arched, oval shaped vessel, with its maximum diameter in the superior part of the body, used for grain storage and for religious purposes. 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 its instability resulted from the 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 0.50m to 1.50m, but there also exist samples which reach a maximum of 2m. 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].
The large dimensions of these vessels raise a geometry problem in the reconstitution phase if the available fragments are small. In this case their position can be determined correctly only if exists the possibility of combining them in a correct way through the break-lines of a jigsaw puzzle.

2. APPROACHES FOR DIGITAL RECONSTRUCTION

There exist several methods of 3D reconstruction of the broken artifacts [3],[4]. The majority of them focus on identifying similarities between boundary type curves that confine the fragments of the vessels. In Figure 1, there is represented a reconstitution model based on jigsaw puzzles reassemble [5].

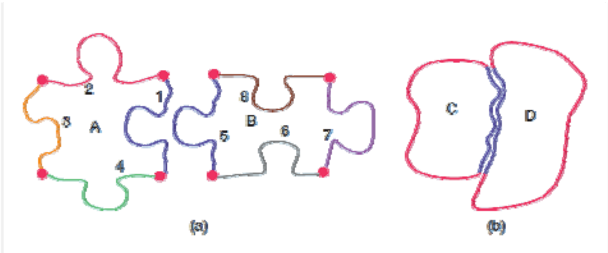

Figure 1. The differences between reassembling commercial jigsaw puzzles and reconstructing broken artifacts [5].

Puzzle pieces have easily identifiable corners (a), highlighted with red dots on Figure 1, that enable the use of image processing programs, which facilitate the problem of uniqueness of the assemblage. In the case of artifact reconstruction, two hypothetic curves (marked with red in Figure 1. (b)) delimit the two fragments. Contrary to jigsaw puzzles, the corners are difficult to detect, the delimitation of the curves is delicate, and in consequence the uniqueness of the reconstitution solution cannot be assured.

Another possible reconstitution method is based on rebuilding the profile of the vessel, which later on is used to generate the entire artifact through an operation that implies rotating the rebuilt profile around the theoretical axes of the vessel.

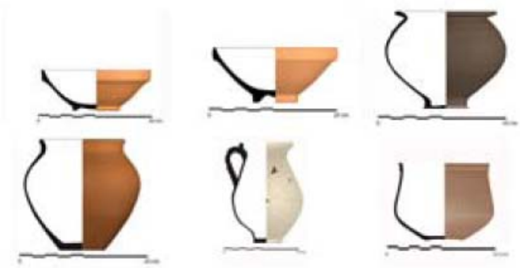

Figure 2. Reconstitution of a vessel using its' profile [5].

There also exist several applications [3],[4] and [5] used with success in automatic reconstruction of ceramic vessels that are based on mathematical functions and algorithms especially developed for digital reconstitution. Usually these are used together with special databases which store the types of vessels that can be automatically reconstituted.

New ways of reconstitution were developed as a combination of puzzle-based concept respectively the profile rebuilding method.

3. RECONSTITUTION OF DACIAN CHIUPS

3.1. Generalities

The Dacian pottery chiup vessels imitate the Greek *Dolia* and *Pythos* vessels, keeping their features with only small adjustments [1],[2]. These types of vessels were used for liquid and grain storage. If being used for liquid storage, before the burning process the vessel has been sunk in a clay and water solution, afterwards it was polished in order to increase its impermeability. Vessels of this category are created using a wheel and then burnt in specially arranged ovens or specially prepared holes.

Archeologists have discovered that these types of vessels are mostly found around the kingdom's capital, 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, they used pottery vessels [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 present inside the fortress can be considered natural, as the quantity of water and grain was higher than the inside of a usual house.

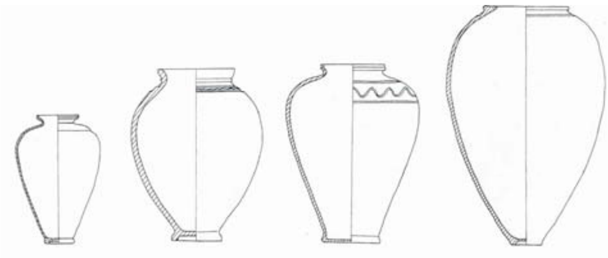

Figure 3. Chiup designs [1].

Considering the vessels' dimensions, the physical reconstruction requires a high amount of effort especially if the pieces found are small regarding their size.

The reconstruction method proposed by this paper is a graphical one, where the pieces are manually assembled using geometric references like: transversal and longitudinal curves, the vessel's symmetry axis and boundary type curves which limit each fragment.

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 is between 2/1 and 3/2 and between the low end diameter and the height between 1/4 and 1/9 [1], [2].
- Another particularity of these vessels is the fact that they are modestly decorated, fact that makes the reconstruction process hard 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.

3.2. The geometrical reconstruction method of the vessels

The method presented in this paper involves the manual assembly of the vessels' fragments using the its symmetry axis determined for every fragment or every group of fragments. A series of longitudinal and transversal curves are used in this respect, which offer the possibility of determining the vessels' axis of symmetry as well as grouping the fragments into segment zones. This method is developed to recreate the chiup type vessels but it can be used for other types, too.

The method requires the following steps:

1. *Identifying vessels of the same type and dimension* (if possible) – this can be achieved easily if in the found fragments one can identify pieces that can lead to an approximation of the vessel's diameter, based on the previous observations referring to the standardization some important dimensions can be determined and then used in the reconstruction process.
2. *The digitization of the vessel's pieces* – is done using laser scanning or any other type of scanning which offers at the end a cloud point that can be used for generating a surface and will not damage the vessel's fragments. 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.
3. *The generation of the transversal and longitudinal curves* – with the help from planes which are perpendicular on the revolution axis or planes which contain this axis. Through successive tries 4 – 5 transversal and longitudinal curves are generated until the direction of the diameter's growth can be established; these directions will be used in order to position and orient the fragment. During this step a circle will be generated in transversal section for each extremity of the pieces using a best fit type method.
4. *Grouping the fragments* – using the diameters of the circles generated at the previous step a series of intervals will be established in which the fragments will be grouped. For each interval a minimum and maximum value will be established and it is tried that for each piece from the same group the two circles will be geometrically created, this time using the transversal curves which indicate the diameter's growth ratio.
5. *Generating the boundary curves* – for each fragment a boundary curve will be generated which will be used for matching pieces from the same group. The assembly will be done manually using the symmetry axis which was determined in a previous step.
6. *The generation of the profile* – after matching the fragments in one group, the

groups will be positioned vertically using a longitudinal profile from a similar vessel if the groups don't have areas which assembly themselves completely. In the most complete section of the vessel a longitudinal profile is generated which will be completed if necessary using tangent relations and plane projections, or the profile of a similar vessel.

7. *The completion of the vessel*:

a) Using the profile generated at the last step, a theoretically generated axis of revolution is used and the whole vessel is generated.
b) Using commands like sweep the missing pieces can be generated one by one using guide curves.

4. CASE STUDY

For validating the proposed algorithm, a case study was performed regarding the reconstitution of a chiup from the patrimony of the National History Museum of Transylvania. The fragments of the vessel were discovered in Gradistea de Munte (Sarmizegetusa Regia) in 1957 by Constantin Daicoviciu.

Figure 4. Chiup fragments in situ (picture from the patrimony of the National History Museum of Transylvania Cluj-Napoca)

1. Identifying vessels of the same type and dimension

The rim of the vessel is formed from the chosen pieces (Figure 5a.) These were digitized and used for determining the diameter of the vessels' top. This part is almost standardized and directly influences the dimensions of all the other parts.

The digitization of the fragments was achieved using a laser scanner with a precision of 5 μm, obtaining an extremely precise 3D model that closely resembles the original physical model. After digitizing this fragment, the dimension of the top of the vessel can be determined through a geometrical construction and vessels with similar dimensions can be identified.

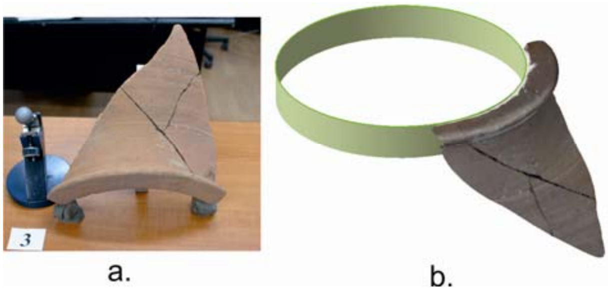

Figure 5. Digitized chiup fragment (a), and the reconstitution of the diameter of the top part (b)

After identifying a vessel having a top part with the same dimensions (Figure 6a.) it has been digitized (Figure 6b.) in order to obtain its' profile, needed later on in the next stages of the digital reconstruction. The vessel has a height of 1.15m and a maximum diameter of 0.95m. The area of the vessel is of 3m^2 and the scanning process duration was of approx. 4 hours, three fragments were obtained, the point cloud having over 30 million points.

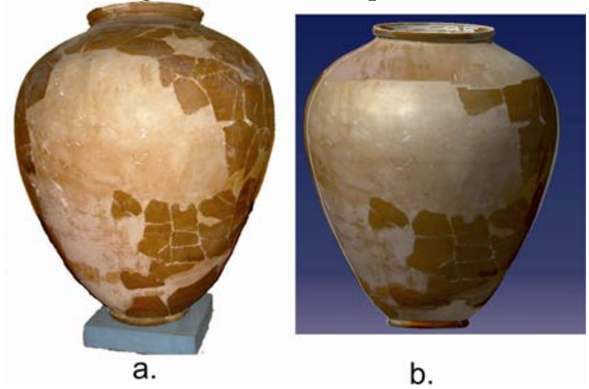

Figure 6. Reconstitution vessel (a) from National History Museum of Transylvania and a digitized vessel (b)

2. The digitization of the vessel's pieces

The fragments were digitized with laser scanning technique, the resulted cloud point (Figure 7.a) has been transformed in a surface (Figure 7.b) on which later on has been applied the texture (Figure 7.c) from the original fragment. (Figure 7.e).

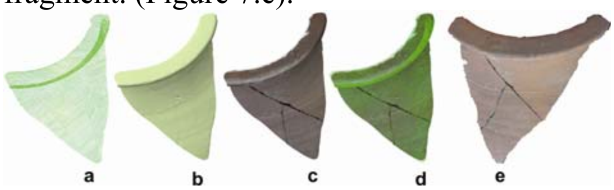

Figure 7. Digitized vessel fragment: a-point cloud; b-surface;, c-textured surface; d-point cloud and textured

surface overlapped; e-fragment discovered at Gradistea de Munte.

3. The generation of the transversal and longitudinal curves

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 of the algorithm at grouping the fragments.

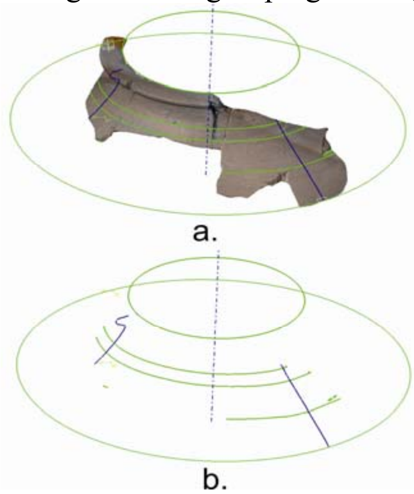

Figure 8. Generation of transversal and longitudinal curves

In Figure 8 is represented a fragment with the adjacent curves obtained from the intersection of the surface with the perpendicular plains on the theoretical axes of the vessel and with the planes that contain this axes. For each of the fragments, there are generated circles with a maximum and a minimum diameter which will be used in the next phase when grouping the fragments on diameter intervals.

4. *Grouping the fragments*

In the case of the present vessel, six segmenting intervals had been established. For each interval the inferior and superior limits were set. Figure 9 represents the limits values and their position on the vertical axes, as well as the distances between the segmenting planes.

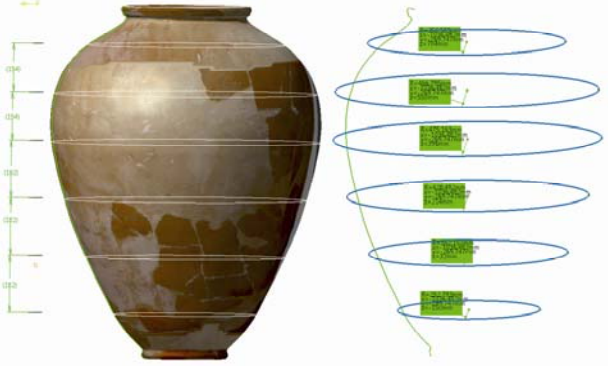

Figure 9. Segmenting planes (left), segmenting limits and their diameters (right)

5. *Generating the boundary curves*

In this phase boundary curves are generated for each fragment of the vessel which separates the surfaces. These are used later on for matching of the component of a certain group of pieces.

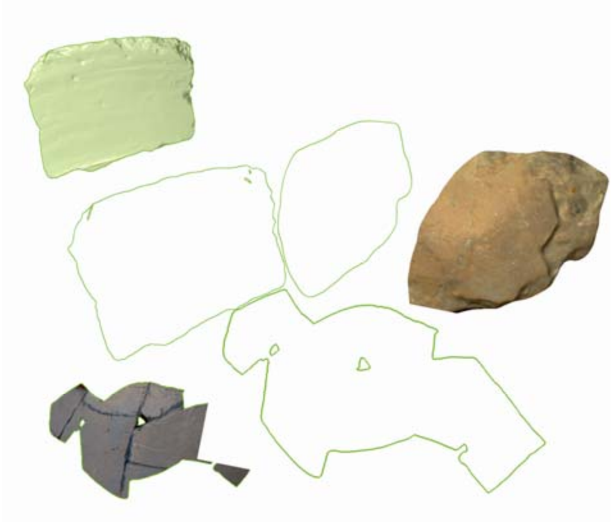

Figure 10. Matching fragments using boundary curves

6. Generating the 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.

7. The completion of the vessel

Using a simple geometrical operation (revolve) the entire vessel is generated.

Figure 11. Intermediary stage (left) and final reconstruction

5. CONCLUSIONS

The method presented in this paper can be applied with success in the case of chiup type

vessels. It is a graphical method which does not imply mathematical calculations in order to offer a correct solution for matching the fragments.
Using graphical methods the symmetry axes of each fragment of the vessel are determined, which later on are used in correlation with other elements for the correct positioning of a fragment.
This reconstruction method is possible due to the particular features of this type of vessels: standardization of the relations between different dimensions, the lack of decorating elements, and the manufacturing process using the potters' wheel which creates a symmetry axis. Compared to reconstruction methods based on automatic matching, this method requires a larger amount of work and in certain situations it may be difficult to be used.
When only smaller fragments exist it may be difficult to distinguish the symmetry axes of the vessel, making it impossible to establish the position of the fragment. Yet this problem may occur in any reconstitution method, even in the conventional one when the vessel is complete.

6. ACKNOWLEDGEMENT

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Reconstituirea vaselor ceramice din familia chiup

Rezumat: Lucrarea propune o metoda de reconstituire a vaselor ceramice dacice, utilizate la depozitarea cerealelor cunoscute sub denumirea de chiup. Acesta era unul din cele mai răspândite vase de provizii din lumea dacică, sunt de dimensiuni mari si reconstituirea lor ridica probleme specifice atat din punct de vedere tehnic cat si geometric. Metoda digitala de reconstituire prezentata in lucrare se bazeaza pe utilizarea scanarii laser si a tehnicilor de modelare specifice. Metoda se bazeaza numai pe operatii geometrice si propune o reconstituire manuala a vasului fara a recurge la matching automat.

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