2020 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Trento, Italy, October 22-24, 2020

Preliminary studies on the volumetric capacity of ceramic from the Neolithic site of Lugo di Grezzana (VR) through 3D graphics software

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***Abstract* – The aim of the study is to obtain an estimate of the volumetric capacity from a selection of ceramic vessels from the Neolithic site of Lugo di Grezzana (Verona, Italy). The method applied involved the use of *Blender*®, a free and open source 3D computer graphics software. This program can calculate the volume from the graphic elaboration of the archaeological drawing of the artifacts. Through the calculation of volume has been possible to obtain an estimation of the total capacity of the vessels, proposing two types of content. The volumetric estimates were later compared between diameter and height of each ceramic vessels, to define the size classes. The research shows that the internal variability of some ceramic shapes could be the consequence of different functional and/or cultural choices. This paper tests a method which could be applied in future research projects.**

Keywords: Vessel capacity, Ceramics, 3D models, Blender, Neolithic.

I. INTRODUCTION

A. The ceramic record

The study takes into account ceramic finds from the Neolithic site of Lugo di Grezzana, which is located in the Lessini Mountains. The site, dated between 5300 and 4900 - 4800/4700 BC cal., has been the object of decades of research directed by the Archaeological Heritage of Veneto Region (since 1991) in collaboration with the University of Trento (B. Bagolini Laboratory, since 1996) up until 2005 [1]. The site represents one of the main pieces of evidence for the understanding of occupation strategies and raw materials exploitation between the end of the 6th and the beginning of the 5th millennium BC [2]. It gave back a considerable amount of artifacts (Fig. 1) that allowed the attribution mainly to the Fiorano culture. This culture is present in northern Italy during the early Neolithic and shows a typical homogeneity in vessels typology. Mug vessels are possibly one of the most distinctive shapes of the Fiorano culture and are often imported into contemporary cultures [3]. Regarding the study of ceramic record, it is important to refer to the digitalization in 3D of some pottery mentioned in this paper through photogrammetry. This work was carried out at TeFALab (Laboratorio di Tecniche Fotografiche Avanzate, unit of LaBAAF, University of Trento) under the technical direction of Paolo Chistè. At the present time, a systematic analysis that evaluates the metric criteria of the ceramics of the Fiorano culture has not yet been carried out [4]. However, for the Neolithic of northern Italy there is a typological classification of the vessels that distinguishes their morphology in relation to the profile, the diameter/height ratio and the size of the mouth [5]. Nevertheless, this classification does not include the volumetric capacity parameter.

B. The calculation of volumetric capacity: the application of computer-assisted calculation through 3D graphics software

The volumetric estimate of a pottery container can be calculated with direct or indirect methods. Direct measurements involve filling the vessel with liquid or solid materials, the latter adaptable to the internal shape. However, this method can’t be applied to the entire ceramic record, both because usually a limited percentage of the potteries are complete or reconstructed, and also for conservation issues [6,7,8]. Indirect measurements, on the other hand, are two-dimensional geometric methods and more recently computer-assisted calculations based on a 3D model. The latter, unlike direct measurements, does not require the availability of the artefact *in situ*, as the measurements are carried out through the use of archaeological drawings, which have a continuous profile from the rim to the bottom, exploiting the principle of symmetry [8]. Pre-protohistoric artifacts often have an asymmetrical and irregular profile and are therefore an exception. The main softwares that can be used to apply the previously described indirect method are: *AutoCAD*®, *Rhinoceros*™ and *Blender*® [8,9]. In addition, other suitable programs as *Kotyle*© [10] and web applications that do not require the installation of a software like *Capacity* [6,11,12]. In this study, the 3D graphics program of choice was *Blender*® [13] since it is free and open source, which allows the users to generate extensions in order to improve it. The estimate of the volumetric calculation was relied on the *3D-Print Toolbox* extension, although different *add-ons* are known to be effective as well [9]. Unlike what other authors have stated in the past [8], nowadays it is possible to create the vector drawing within the program without external processing, directly importing the starting image.

II. MATERIALS

The methodological protocol was applied to a selection of 20 archaeological drawings (Fig. 3). The sample analyzed was chosen taking into consideration typological and technological data. Twelve drawings illustrate whole artifacts, with a continuous profile (from the rim to the bottom of the vessel), while the others are only partially preserved. Hence, in order to reconstruct the original morphology, the drawings of the fragmented samples were integrated through the study of whole ceramic vessels belonging to the same typological class. For this group of samples is essential to keep in mind that the capacity estimate will have a greater degree of inaccuracy. The development of the operational methodology allowed the identification of the minimum requirements that the ceramics and the drawings must have. First of all, through the graphic representation it must be possible to obtain the diameter and the internal profile. Furthermore, it is necessary to know the scale of representation because the calculation of the volume must be obtained on a 1:1 scale. Lastly, it was observed that using a high-resolution drawing (d.p.i.) allowed a more accurate 3D model of the interior wall of the vase. During the study were used these technical specifications: processor (AMD Ryzen 3 2300X), RAM (16 GB), graphics card (NVIDIA GeForce GTX 1660 Ti), display (1920X1080 pixels, 24-bit color), input (three-button mouse), Blender® (version 2.82).

Fig. 1. Vessel from the Neolithic site of Lugo di Grezzana (Photo P. Chistè - LaBAAF) [1]

III. METHODS

The calculation of the volumetric capacity was carried out by importing each drawing into the 3D graphics program. The image was imported through the *Images as Planes* command (Add > Image > Images as Planes). When selecting the image to be imported, it is important to provide the program the exact graphic resolution of the file (d.p.i.). This step is necessary in order to avoid any changes in the original dimensions of the imported drawing which would therefore entail an incorrect estimate of the volume. If is not uploaded an image on a 1:1 scale, the drawing must be scaled to its original size. This operation is possible in *Object Mode* (Properties editor > Object properties > Scale X / Y). For example, a drawing on a 1:3 scale will have X and Y values equal as 3. Once this phase is finished, is possible to continue with the generation of a curve, still staying in *Object Mode* (Add > Curve > Bezier). The subsequent modelling of the curve takes place in *Edit Mode*, which allows to modify the path along the X and Y axes and divide it into several segments (right click > Subdivide) in order to trace the underlying drawing. After obtaining a 2D profile of the inside of the vessel, it is necessary to generate a line (*Path*), which will correspond with the rotation axis of the curve itself (Axis Object) and with the midline of the archaeological drawing (Object Mode > Add > Curve > Path). Once the rotation axis is fixed, the curve can be rotated 360 degrees. This procedure takes place in the *Edit Mode* (Properties editor > Modifier properties > Add Modifier > Screw). As soon as the command is selected, it is necessary to define some options, namely: the Cartesian axis to which the curve is oriented (Axis, in this case the X axis), the object around which the rotation takes place (Axis Object, in this case the midline generated previously) and lastly the number of "segments" the revolution is divided into (Steps), as a greater number of these entail a better graphic resolution and consequently a more accurate estimate of the volume (the shading was not realized because rendering is unnecessary for the estimate of the volume). The rotation surface is converted into a solid by obtaining, in *Object Mode*, a mesh made of vertices, edges and faces (Object > Convert to > Mesh from Curve/Meta/Surfing/Text). The essential step for obtaining the volume is the closure of the solid at the rim and at the base. This process is achieved by creating new faces, originating at the end of the solid by selecting the extreme edges. In order to obtain these faces it is necessary to select *Edge* select in the *Edit Mode* (alt + left click on the Edges > right click > New Face from Edges). Once the solid is closed, the calculation of the volumetric capacity is performed automatically using the *add-on*: *3D-Print Toolbox* (available since 2.67 version, released in May 2013). Once the solid has been selected in *Object Mode* and the *Volume* option selected, the volume value expressed in cm^3 will be available in the *Result* box (Fig. 2). The validity of the procedure was previously established during the formulation of the method, through the graphic reproduction and the volumetric calculation of a cylinder of known dimensions (r = 5 cm; h = 20 cm). This procedure allowed to calculate the absolute and relative error in the method developed, taking into account the tolerance. The latter is characterized by different causes such as: the inherent uncertainty regarding the measured object, the conservation status, the operator, the procedure and the measuring instrument used. Taking these issues into account, it was calculated a tolerance of about ± 1 mm.

$$\text{Absolute Error (EA)} = (Vol_{max}-Vol_{min})/2 = 70.6889 \text{ cm}^3$$
$$\text{Relative Error (RE)} = EA/Vol_{avg} = 0.0449$$
$$\text{Percentage Error (PE)} = RE\text{x}100 = 4.49\ \%$$

The methodological approach was subsequently extended, considering two hypothetical types of contents, a liquid and a solid one. As to what concerns the estimate of the capacity, it has been treated converting the measure from cm^3 to ml (1 cm^3 = 1 ml). Instead, in the case of solids contents has been calculated the weight (grams) of three types of cereals such as: whole barley, emmer and naked wheats, selected accordingly to the data collected from archaeobotanical analysis carried out for the site of Lugo di Grezzana [14]. The weights were estimated in relation to the bulk density of each kind of cereal (whole barley 0.61÷0.69 g/ml, emmer 0.47 g/ml e naked wheats 0.54 g/ml) [15,16] and the volumes of the containers, according to the following formula:

$$\text{Weight} = \text{Bulk density x Volume}$$

Lastly, metrical analysis were carried out through the correlation of the maximum volumetric capacity (cm^3), while the depth of the vessel obtained from the ratio between diameter and height (Ø/h), and the typology [5].

Fig. 2. Summary scheme of the operating methodology performed with Blender®

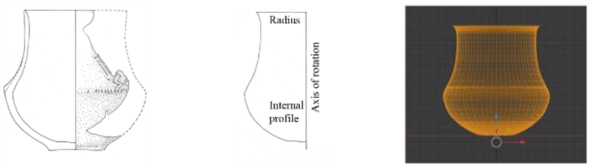
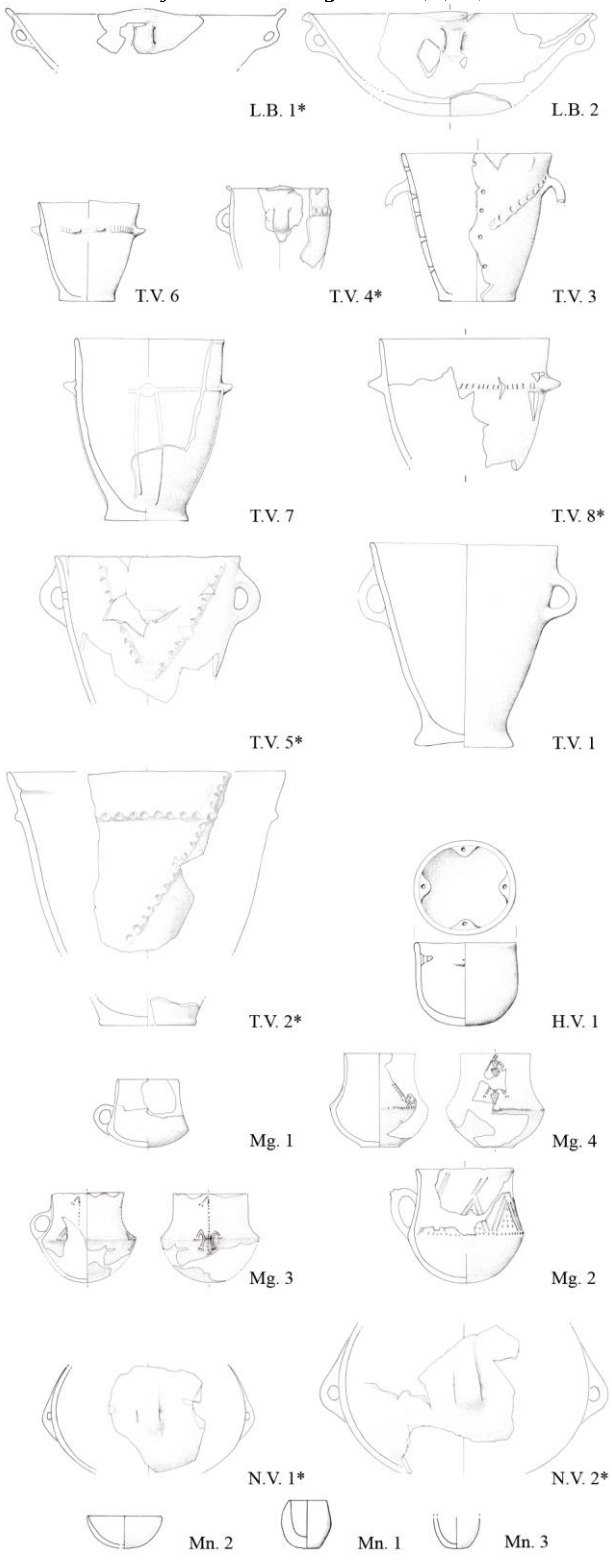


Fig. 3. Typological table of the samples analysed during the study. Scale drawing 1:10 [1,2,17,18]



*Legend: H.V. = Internal Handles Vessel; LB. = Large Bowl; Mg. = Mug; Mn. = Miniaturistic; N.V. = Necked Vessel; T.V. = Truncate cone-shaped Vessels; * = Partially preserved;*

IV. RESULTS

The calculation of the volumetric capacity allowed to provide an estimate of the capacity (ml) and the weight of the different contents (g), summarized in table 1. At the same time, it was possible to correlate the values determined by the computer-assisted calculations with the ratio between Ø / h, summarized in table 2. Subsequently, the elaboration of the data took place through the compilation of a scatter plot, reporting the volumetric capacity in the X axis and the Ø/h ratio in the Y axis (Fig. 4).

Table 1. Summary of contents estimates (= partially preserved)*

Samples	Estimate Liquid Content (ml)	Estimante Solid Content (g)		
		Whole Barley	Emmer	Naked Wheats
L.B. 1*	5276	3218÷3640	2480	2849
L.B. 2	6959	4245÷4802	3271	3758
T.V. 1	5646	3444÷3896	2654	3049
T.V. 2*	17307	10557÷11942	8134	9346
T.V. 3	2967	1810÷2047	1394	1602
T.V. 4*	1329	811÷917	625	718
T.V. 5*	5941	3624÷4099	2792	3208
T.V. 6	944	576÷651	444	510
T.V. 7	3961	2416÷2733	1862	2139
T.V. 8*	5235	3193÷3612	2460	2827
H.V. 1	925	564÷638	435	500
Mg. 1	125	76÷86	59	68
Mg. 2	1825	1113÷1259	858	986
Mg. 3	772	471÷533	363	417
Mg. 4	839	512÷579	394	453
N.V. 1*	6054	3693÷4177	2845	3269
N.V. 2*	13378	8161÷9231	6288	7224
Mi. 1	53	32÷37	25	29
Mi. 2	158	96÷109	74	85
Mi. 3*	59	36÷41	28	32

Through the interpretation of the scatter plot, it was possible to group the ceramic samples into four size groups:

Group 1: represented by four samples (one of which is partially reconstructed). The ceramic samples are characterized by a volume lower than approximately 200 cm^3, containing between 25 and 109 g of solid content and a Ø/h ratio is between 0.76 and 2.23. The wide range of the latter parameter is due to the fact that within the group there are different degrees of depth. Miniaturistic forms are in this group for a reduced volumetric capacity. In this group is also present a mug that differs from other equal typological samples for its lower volumetric capacity.

Group 2: represented by five samples (one of which is partially reconstructed), whose ceramic forms are characterized by a volume between 750 and 1800 cm^3, containing between 363 and 1259 g. of solid content and a Ø/h ratio between 0.74 and 1.16. Within the group are included forms that are mainly represented by mugs, two truncate cone-shaped vessels and the internal handles vessel

Group 3: represented by seven samples (three of which are partially reconstructed). The ceramic forms are characterized by a volume between 2900 and 7000 cm^3, containing between 1394 and 4802 g. of solid content. At the same time, the group is divided into two subgroups, which differ from each other for their depth (3a and 3b). The first subgroup (five samples) is represented by a Ø/h ratio between 0.44 and 0.97, mainly consisting of truncate cone-shaped vessels with the only exception of a neck vessel. The second subgroup (two samples) differs by a ratio of Ø/h between 2.74 and 3.23, consisting of the two large bowls.

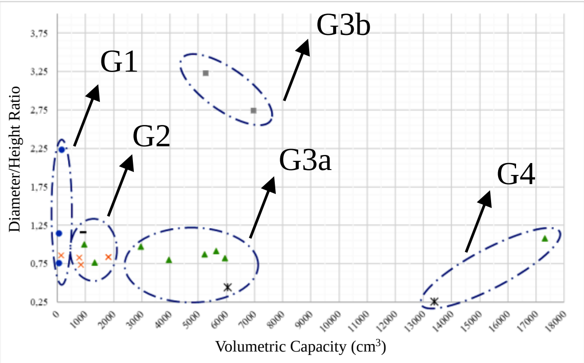
Group 4: represented by two samples (both reconstructed), of which one necked vessel and one truncate cone-shaped vessel. They have a volumetric class, an estimate of solid content and a Ø/h ratio that differs from all the previous groups. They have a volume between 13000 and 17500 cm^3, a capacity of solid content between 6288 and 11942 g and a Ø/h ratio between 0.25 and 1.08.

Table 2. Summary of results (= partially preserved)*

Samples	Volume (cm^3)	Ø/H Ratio	Size Group
L.B. 1*	5276	3,23	G3b
L.B. 2	6959	2,74	G3b
T.V. 1	5646	0,92	G3a
T.V. 2*	17307	1,08	G4
T.V. 3	2967	0,97	G3a
T.V. 4*	1329	0,77	G2
T.V. 5*	5941	0,82	G3a
T.V. 6	944	1	G2
T.V. 7	3961	0,80	G3a
T.V. 8*	5235	0,87	G3a
H.V. 1	925	1,16	G2
Mg. 1	125	0,86	G1
Mg. 2	1825	0,83	G2
Mg. 3	772	0,83	G2
Mg. 4	839	0,74	G2
N.V. 1*	6054	2,24	G3a
N.V. 2*	13378	3,85	G4
Mi. 1	53	0,76	G1
Mi. 2	158	2,24	G1
Mi. 3*	59	1,14	G1

As emerged from the results, some ceramic forms that have similar Ø/h ratios and the same typological classification, can have different volumetric capacities. This statement is noticeable, for example, in the class of truncate cone-shaped vessels. This type of pottery has a Ø/h ratio with a very limited (between 0.77 and 1.08), conversely the volumetric capacity has a much wider degree of variation (between 944 to 17306 cm^3).

Fig. 4. Scatter plot between volumetric capacity (X axis) and diameter/height ratio (Y axis) Legend: Internal handles vessel (–); Large bowl (■); Miniaturistic (●); Mug (X); Necked vessel (✱); Truncate cone-shaped vessel (▲);



Although most of the truncate cone-shaped vessels appear to have a capacity that varies between 2900 and 7000 cm^3 (Group 3a), three samples have respectively a lower (T.V. 4* and T.V. 6 in Group 2) and a greater volumetric capacity, although the latter reconstructed (T.V. 2* in Group 4). At the same time, this oscillation is observable, although in minor way, in the mug's class. Most of the samples belong to Group 2 with a volumetric capacity between 750 and 1800 cm^3, with only one case within Group 1 (Mg. 1), which can be considered as a miniaturistic mug.

V. DISCUSSION

This methodological protocol has led to obtain an analysis of the volumetric capacity of the vessels and to propose a division into size groups, which could be a reflection of different functional and/or cultural choices, as indicated by the change in volume found within some typological classes, such as truncate cone-shaped vessels and mugs. The observations reported are, however, preliminary: first of all because for some typological classes it was not possible to consider a group of samples adequately large; in addition, some typological categories are absent, such as bowls and jars, whose base is rarely preserved. The latter characteristic obviously makes it difficult to reconstruct the original height and consequently the calculation of their capacity. Another important factor is that the evaluation of the volumetric data is usually, in literature, correlated with other criteria. In addition to the dimensions and typological aspects taken into account in this paper, it would also be appropriate to consider the technological aspects such as: the petrographic analysis (*fabric*), the surface treatment processes (smoothing, polishing, slip) [19], the use-wear and organic residues [20,21,22]. Only through a complete analysis of these parameters is generally possible to distinguish the ceramic samples into five functional categories such as: storage, cooking (food preparation with heat), food preparation without heat, serving and transport. [23]. Therefore, only with the systematic application of the method discussed in this paper and the evaluation of further investigation parameters, it will be possible to explain the functionality of the ceramic samples from Lugo di Grezzana site.

VI. CONCLUSION

This study aimed to propose a methodology for the volumetric calculation of ceramic samples from the Neolithic site of Lugo di Grezzana, with the aid of a 3D graphics software, concluding that:

1- The use of the Blender® allowed to work directly on the published bibliography available, with no need for direct interaction with the object of study and to obtain a computerized calculation of the volume, in just in a short amount of time and just a few steps. As for the resolution of the software used, it allows to obtain very reliable results, expressing the total volume in cm^3 (up to the fourth decimal place).

2- At the same time, the application of the method to ceramic artefacts must consider the tolerance. The latter is determined, not only by parameters associated with the vessel itself (asymmetries, conservation status), but also by the graphic reproduction. For this reason, the results obtained must be considered as estimates of the volumetric capacity, in any case proving sufficiently valid to be applied to an archaeological study.

3- The results emerged must be considered partial since only through the application of the method to a sufficiently large group of samples, not only from the Lugo di Grezzana site but also from contemporary archaeological contexts, could clearly define the vessel capacity for each typological classes.

4- The interpretation of scatter plot, made by the correlation between the volumetric capacity and the diameter and height ratio, led to the creation of different size group that contain different ceramic shapes. In fact, within some typological classes, can be observed a different degree of variability. Such variation could be a consequence of different functional uses and/or different cultural models.

5- In general terms, the study of vessel capacity is one of the parameters necessary for the functional understanding of the artifacts. However, the volumetric data alone is not enough and must be correlated with the multidisciplinary study of the ceramic record and the archaeological context.

The results obtained highlight the informative potential of the method applied starting from the use of the 3D graphics software Blender®. Future studies aimed at investigating this aspect in a systematic way will allow the gain of more information about the functionality of ceramic vessels.

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