Manual by Vasiliki Lagari
(parts of the manual are inspired and written according to the manual written by Chiara Piccoli for her course "Computational Methods in Archaeology" offered from Leiden University)
Instructors: Vasiliki Lagari

3D Reconstruction in Blender

USER'S INTERFACE

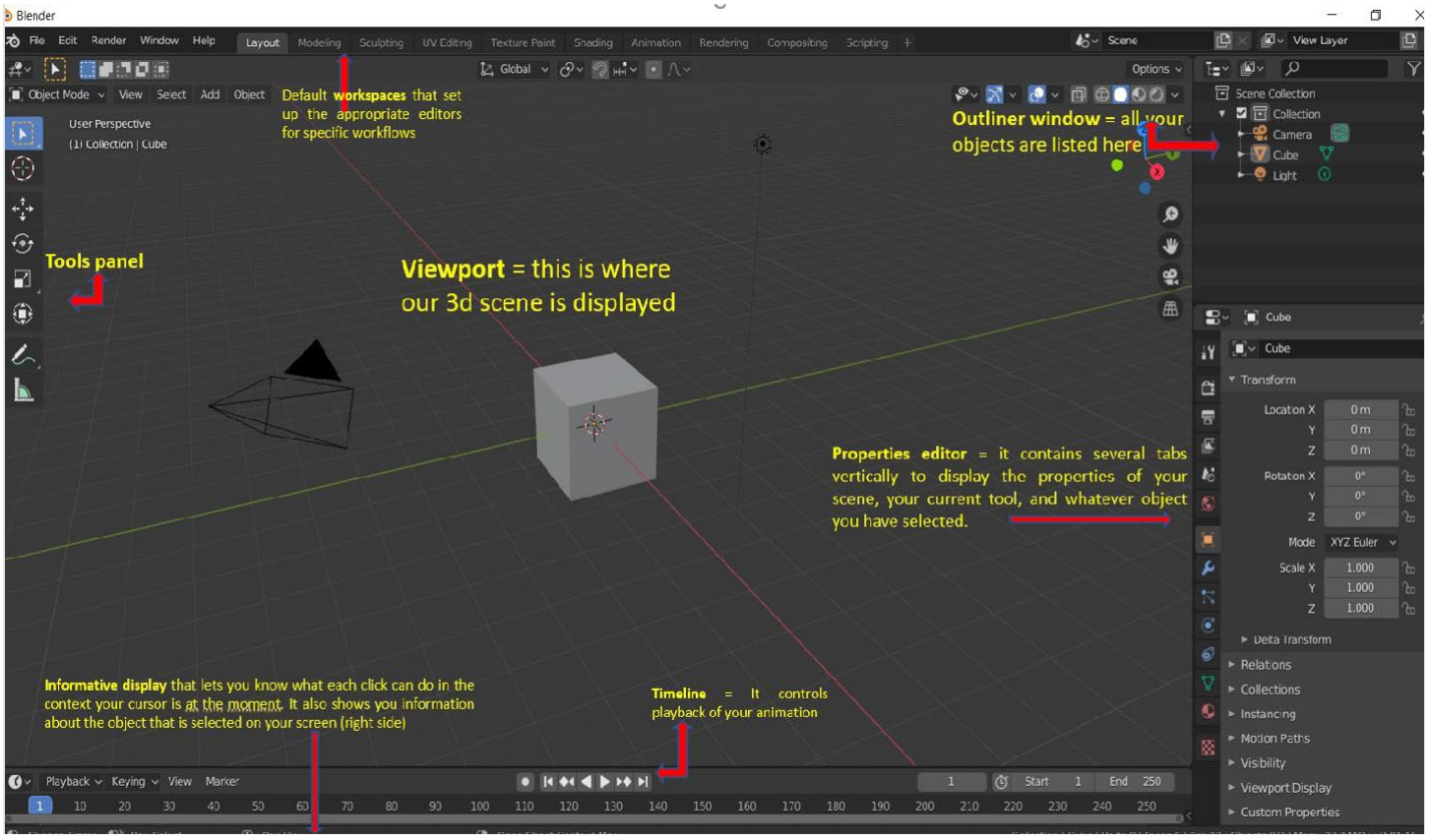

Figure 1

IMPORTANT:

- If the Tools panel is not shown on the left side of your screen, hit **T** on your keyboard (shortcut key for the Tools panel) or left click on the arrow to expand the menu **(Fig. 2)**.
- By pressing **N** (or left click on the arrow on the right next to the gizmo) you open additional quick settings which include your item's

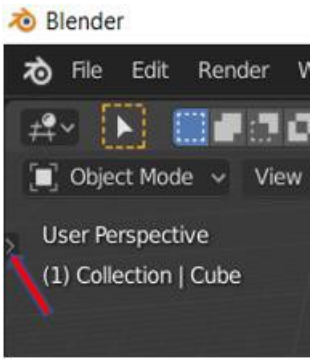

Figure 2

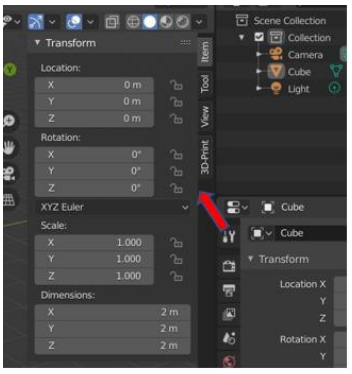

Figure 3

transformation data and other viewport options **(Fig. 3).**

- Click **1** on your Numpad and you go from **User Perspective** to the **Front Orthographic view / 3 = Right Orthographic view / 7 = Top Orthographic View / Ctrl+1 = Back Orthographic view / Ctrl+3 = Left Orthographic view / Ctrl+1+7 = Bottom Orthographic view / 9 = it is used to switch the view** (e.g. from Top orthographic to Bottom orthographic) **(Fig. 4)**. All the views can be also accessed by clicking on the **gizmo** axes **(Fig. 4).**[1]

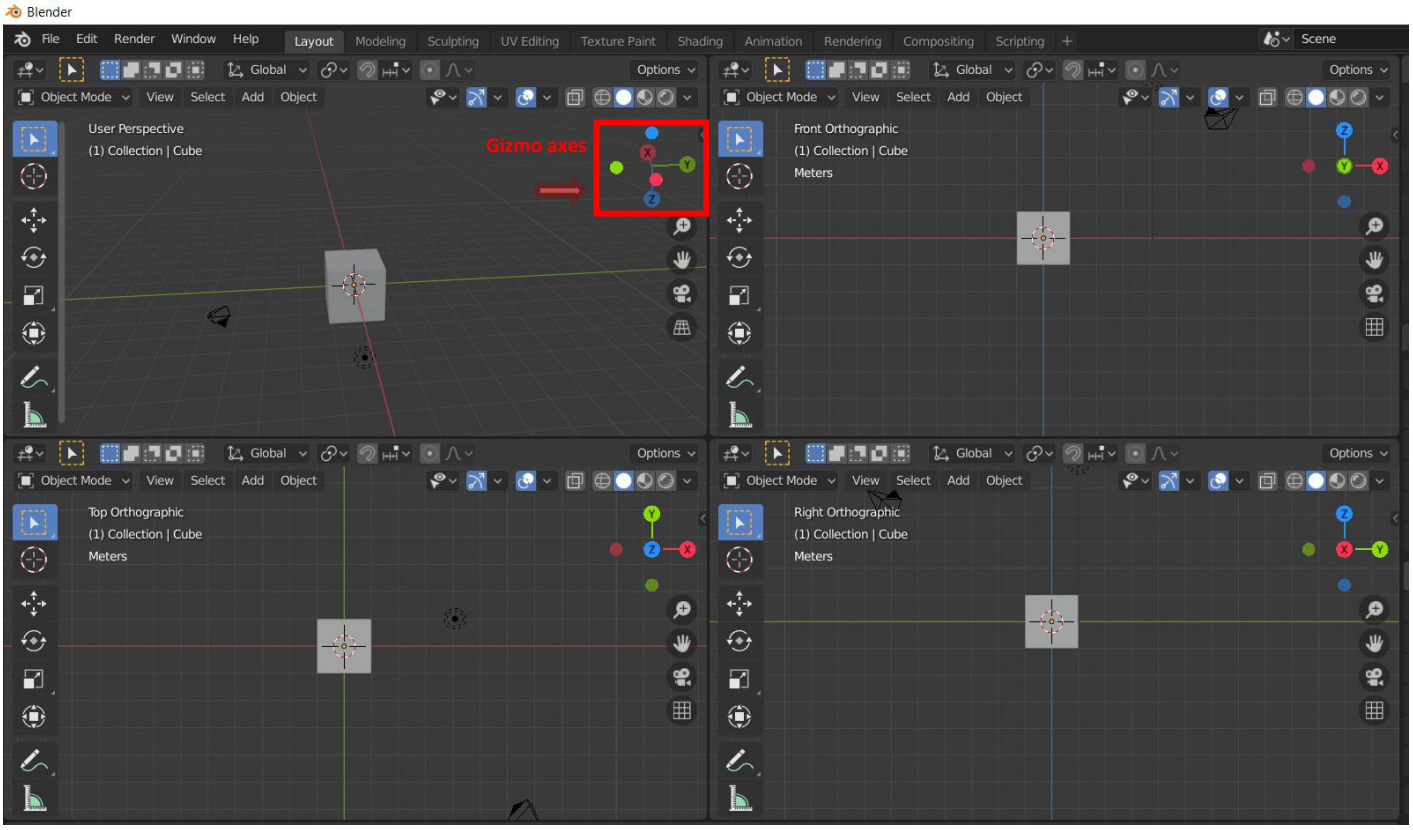

Figure 4

- Manipulate your object with the tool of the Tools panel **(Fig. 5).** When one of the **Move, Rotate, or Scale** tools is active, the respective **gizmo** is shown in the center of the object. A gizmo allows us to operate the tool selected by clicking and dragging one of the colored axes **(Fig. 6).** The **Transform** tool contains all the transformation gizmos in one (move, rotation, scale). **Gizmos** can be activated also from the dropdown menu of the **Gizmo** box **(Fig. 7).**

[1] An extra way for those without a numpad on their keyboard is to go to Edit Menu➔Preferences➔Input➔**Emulate Numpad**. Now, the top numbers on the keyboard can be used instead of the numpad. The downside of this is that in **Edit Mode** the 1, 2 and 3 buttons are used as shortcuts to interchange between vertices, edges and faces. However, this can be restored by deactivating the **Emulate Numpad** option.

Figure 5

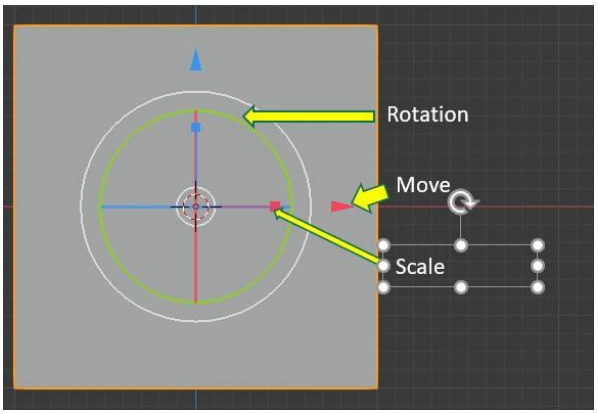

Figure 6

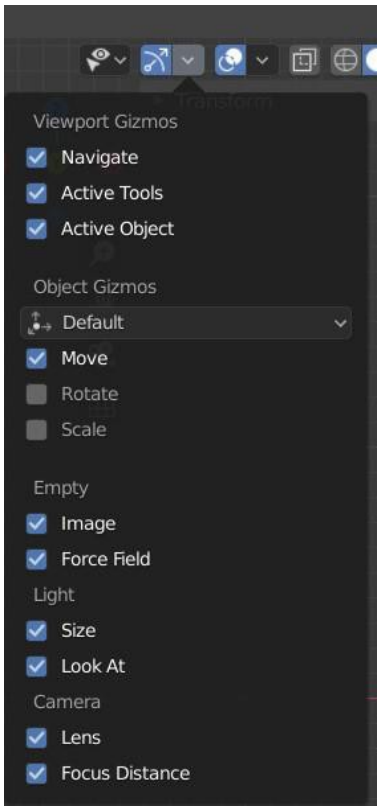

Figure 7

- There are **shortkeys** for every possible operation in Blender. Memorizing common mouse actions and numeric keypad hotkeys in Blender or common keyboard hotkeys and shortkeys in Blender's 3D View help you work more efficiently and faster in Blender. In relation to the transformation operations we referred to in the previous steps, these can be accessed easier by pressing the following keys: **G** for move **(G + Z/X/Y** moves the object towards a specific direction), **R** for rotation (**R + Z/X/Y** rotates the object to a specific axis), (**S + Z/X/Y** scales the object to a specific axis). Left click to lock any of your operations.

- **Object Modes** are an object-oriented feature, which means that the available modes vary depending on the selected active object's type – most of them only enable the default Object Mode (like cameras, lights, etc.). The default mode, available for all object types, as it is dedicated to Object data-block editing (e.g. position, rotation, size), is the **Object** mode **(Fig. 8)**. The **Edit** mode is dedicated to the "shape" of the objects. While in edit mode the structural parts of an object are visible (vertices/edges/faces for meshes, etc.). Select the ones you want to be visible and to edit by clicking on the respective icon **(Fig. 9)** or by pressing **1** (for vertices), **2** (for edges), or **3** (for faces) on your keyboard.

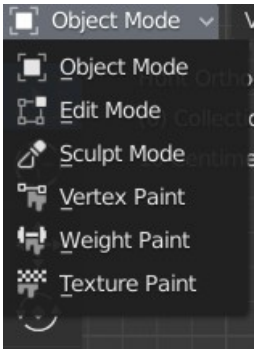

Figure 8

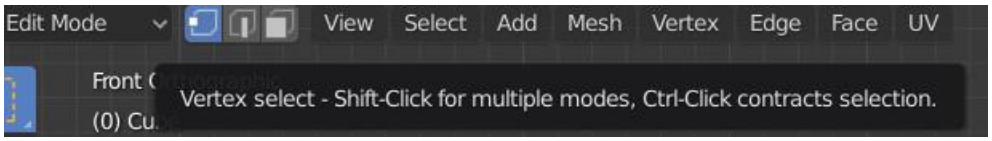

Fig. 9

- **Ctrl + Z** to return to previous steps.
- **H** to hide selected.
- **Alt + H** to reveal all.
- Select multiple objects by holding **Shift.**
- **Ctrl + J** to join selected objects.
- **Spacebar** to search for tools and commands (click on the Edit menu, select **Preferences**, and from the **Keymap** window click on Spacebar Action➔**Search**).
- Left click and drag for **box selection.**
- **Save your sessions regularly.** It is helpful to save different stages of your project with different names. This way you can go back and restart from a certain point in case you are not satisfied with the result.

NAVIGATION IN BLENDER

- **Left click** on any object to select it.
- **A** to select all objects and **Alt+A** to deselect all.
- If you click and drag on your **gizmo (Fig. 10)** you will be able to rotate your object in User perspective [or simply by holding down the middle mouse button **(MMB)**].
- To move the view area (pan), click on the hand icon **(Fig. 11)** or hold down **Shift+MMB.**

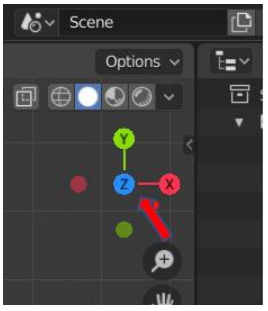

Figure 10

Figure 11

- To **recenter** your view, go to **View** box and select the **Frame Selected** tool (or just click **Numpad .**). This will reframe the perspective to focus on your selected object.
- **Zoom in/out** with your +/- keys on your numbad, or by selecting the magnifying glass (next to the hand icon) or by using the scroll wheel of your mouse.

(useful links, they are introductory for Blender 2.80 but the tools presented apply also for 2.92)

https://www.youtube.com/watch?v=ILqOWe3zAbk

https://www.youtube.com/watch?v=8XyIYRW_2xk

https://www.youtube.com/watch?v=hTL6AKR8YDs

THE MATERIAL

The object involved in the manual was first used for the author's internship and the material was provided by Dr. Joanita Vroom, a specialist in ceramics and professor in Archaeology of Medieval and Early Modern Eurasia in Leiden University. The vessel **(Fig. 12)**, of which only the lower part of the body together with the bottom are preserved, was found in Amman citadel and brought to Leiden by Henk Franken in ca. 1960s/1970s. The preliminary hypothesis was that it could be placed chronologically in Late Antiquity-Early Islamic while its function remained a mystery. After a more thorough bibliographical research prompted by the required stage of reconstruction, probable parallels to the object were discovered in Uscatescu's article on the ceramics from Yaras, in Jordan (Fig. 5) characterizing the object as a cooking pot of the early Islamic period (Uscatescu 1996, 189, **Fig. 13**). A further corroboration of this theory arrived from the book Pottery and Potters **(**Homès-Fredericq *et al.* 1986, 209, 224, 235) where similar vessels were included in the images[1].

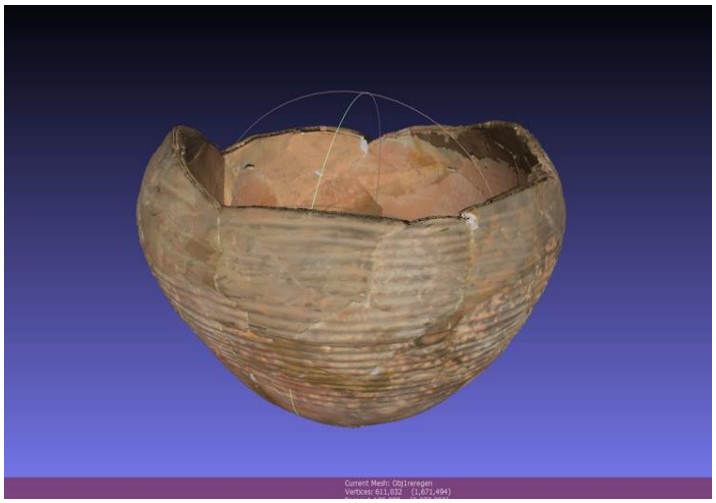

Figure 12

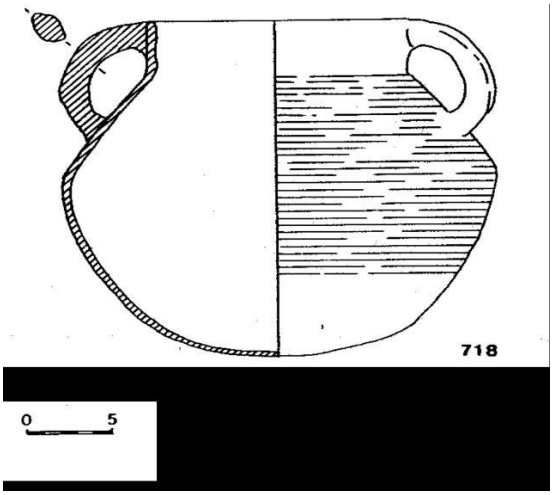

Figure 13

The pot in question was scanned with the NextEngine laser scanner and its mesh was acquired after the composition of different scans in Meshlab (open source software). From there, the profile was semi-automatically produced by using the Adobe Acrobat DC program, while the final stage took place in Blender where the profiles generated by the former were combined with profiles of parallel objects for the

[1] This form of vessel appears continuously during Roman, Byzantine and Islamic period. The parallel that was chosen for the reconstruction is the closest in shape and size according to our subjective estimations.

"anasynthesis" of the complete shapes. This process is, also, helpful in cases that drawings are absent, and the only source of information is the physical object (physical-to-digital process) (Raja *et al.* 2008, 2-3).

In other words, what was attempted was a ***Reverse Engineering*** (RE) method with tools that are user-friendly to (non-experienced) archaeologists. These tools are incorporated in a specific strategy that complies with the basic rules of RE, namely the scanning, the point cloud processing, the data processing and the reconstruction of the final 3D solid model[2].

[2] Similar examples can be found in the articles by Jadhav *et al.* where they use the *segmentation technique* as the last step in order to convert a point cloud into a solid geometry, and by Fragkos *et al.* who focused on the digital restoration of an archaeological find by applying the *"fitting surface modelling"*.

DIGITIZING THE PROFILE(S)[3]

1) Open Blender 2.81 and press ESC or click randomly to get rid of the welcome screen. Select the cube and press **Delete** on your keyboard (or right click and Delete from the **Object Context Menu**).
2) Go to the Edit menu, select **Preferences**, and from the **Keymap** tab choose **Select With: Left (Fig. 14).**

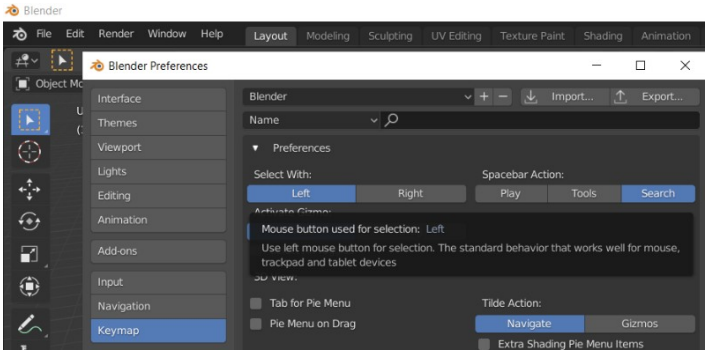

Figure 14

3) Open the **Scene Properties** tab from the **Properties Editor** panel and set the Unit System to **Metric,** Rotation to **Degrees** and Length to **Centimeters (Fig. 15).**
4) Hover our mouse over the 3d viewport and press 1 on your numpad to enter Front Ortho view (or use the gizmo).
5) It is time to import our **reference** images that will help us to digitally reconstruct the vessel. Press **Shift+A** and the **Add** dialog box opens. Select **Background** under **Image** option. Navigate to the file location where you stored the workshop's material and load the image with the name "Profile_scanned_object". Another way to import the image is to directly drag it from its folder and drop it into the Blender environment (**Alt+C** to put it in the center).

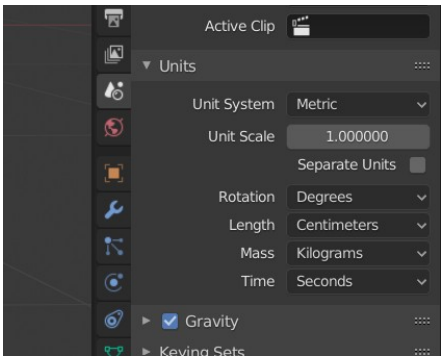

Figure 15

6) You, also, need to add the profile drawing of the parallel object in order to create a complete profile for our reconstruction. Follow the steps described above and load the image with the name "Picture_2_parallel".
7) Go to the **Outliner window** and notice that the images are identified as *Empty* and *Empty.001.* Rename them by double clicking on them.
8) Turn off the visibility of the parallel profile by hitting the eye icon on the Outliner window.
9) Select the **Measure tool** from the Tools panel. There is a real measurement on our image indicated by a green line. The distance between the two edge points is 252.618 mm = **25.2618 cm**.

[3] Part of the following process is inspired by Chiara Piccoli' s course tutorial *"Computational Methods in Archaeology".*

10) Click on the first point on the left and drag your mouse to the second point on the right. Release and you will get the value that Blender gives you. This value is according to the base scale value 1.000000 (**Unit Scale**) when the Unit System was set. Altering this value changes the proportional size of the grids. For example, a 1:1 ration between Unit System and Unit Scale (both 1.0) means that both system and grid scale match.

11) To better understand this press **Shift+A** and add a cube from the **Mesh** options. Go to **Edit Mode** by pressing **Tab** on your keyboard. Check the **Edge Length** from the **Viewport Overlays menu (Fig. 16)** and the size of each edge will appear (200 cm).

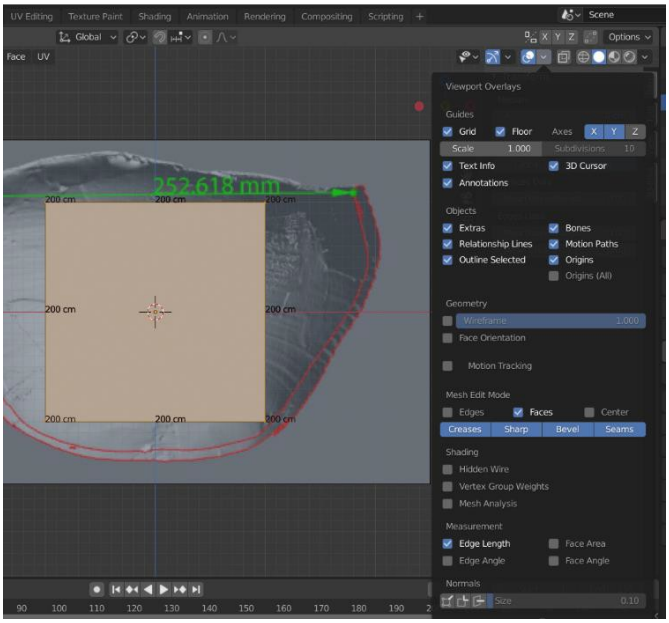

Figure 16

12) If you change the unit scale to 0.5 the grid squares will get bigger and each side of the cube will be of 100 cm value now. And at 1:2 (unit scale 2) a smaller, tighter grid is shown because more sub-units are visible per system base unit making the cube appear larger and each side being of 400 cm length.

13) Set the dimensions of the cube according to the scale bar available (in our case 25.2618 cm) by pressing N and accessing the item's properties.

14) Now, select your image and scale it until the line with the measurement matches the length of one of the cube's edges. Your image is now scaled.[4]

15) **Ctrl + A** to apply our transformations (Scale). Applying transform values essentially resets the values of object's location, rotation or scale, while visually keeping the object data in-place. The object origin point is moved to the global origin, the rotation is cleared, and scale values are set to 1.

16) Having our scale set correctly we turn on the parallel drawing's visibility.

[4] Apparently, we need to change the scale in order to match our actual object's measurements. By applying simple math (rule of three) the unit scale has to be set to 0.06687 (1:0.06687). We see that the value now is very close to the real one (add more decimals to the unit scale if you want to be even more accurate.

17) Hit on **Select Box** (Tools panel) and left click on the parallel drawing to select it. Take a look at the **Image properties** panel from the Properties Editor. Check the **Opacity** option and adjust it to 0.300 (or to a value upon your preference) to have both images visible **(Fig. 17)**.

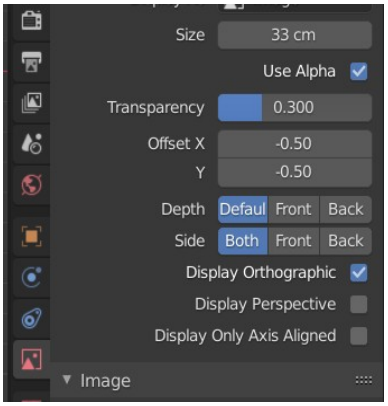

Figure 17

18) Hover over the edges of the image and notice how they turn to bright yellow color. Square handles appear on the 4 corners. Click on one and drag to fit the image to match the original profile (or **S** to scale it). Move it if needed by pressing **G** on the keyboard and move your mouse to the direction you want. The position is locked by left clicking. The goal is match the right profile **(Fig. 18)**. The vessel is not completely symmetrical possibly due to deformations ensued while it was buried or the way it was manufactured.

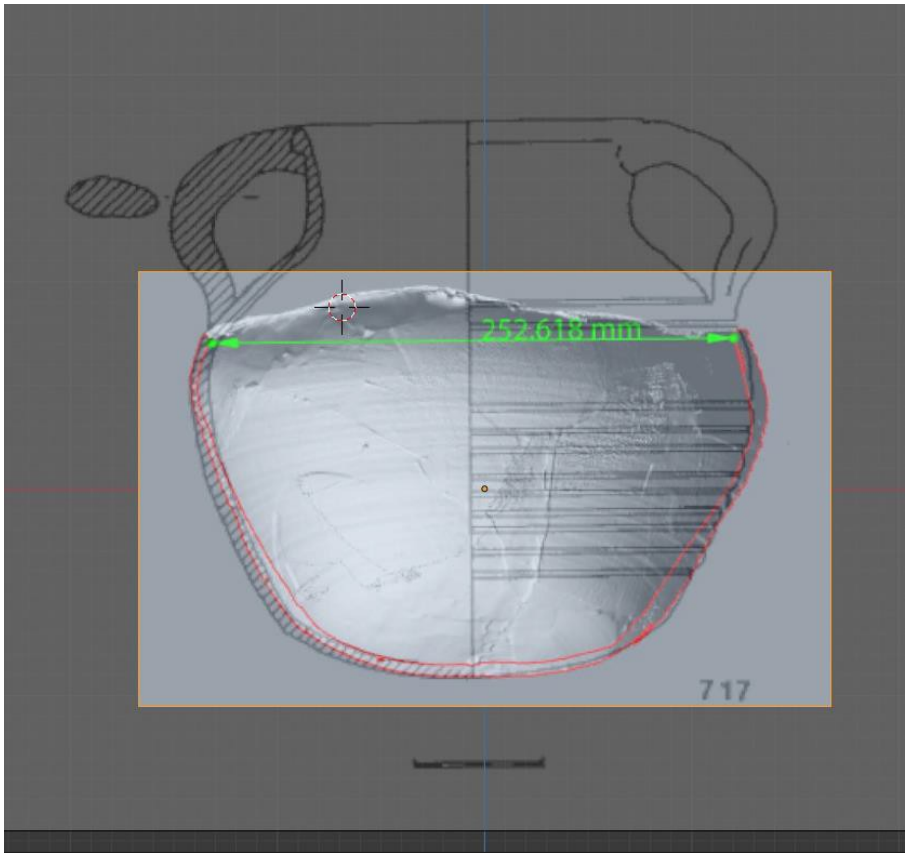

Figure 18

19) Now select the cube again, go to edit mode (hit tab on your keyboard) and make sure that you are on vertex mode.

20) Press **A** to select all the vertices, press delete on your keyboard and choose "vertices". By doing so we have deleted the cube's geometry but not its **origin point**. Each object has an origin point. The location of this point determines where the object is located in 3D space. When an object is selected, a small orange circle appears, denoting the origin point. The location of the origin point is important when translating, rotating or scaling an object. This is a trick to easily create an empty object that we can use to start adding points along the sherd's profile.

21) To add one point on each target location: **CNTR + SHIFT + RMB**. Start from position **START (Fig. 19)** on the image and continue to use CNTR + SHIFT + RMB to finish on position **END**, thus leaving the profile open towards the center. The start and end points must be vertically aligned along the black vertical line in the drawing Start from the bottom part and follow the outline of the original vessel. Continue with the parallel vessel when the outline of the preserved one stops.

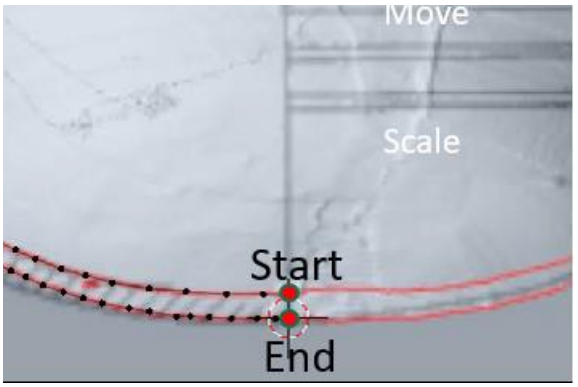

Figure 19

22) Be careful to follow to trace the preserved vessel's profile for the lower part and continue with the parallel's vessel profile for the upper part. **We want to reconstruct the complete vessel.**

23) **Skip** the handle.

24) If you would like to adjust some vertices' position, select the vertex and use G to reposition it. If you need to add vertices at some locations, switch to edge select mode (se image above), select the edge where you would like to add an additional vertex, right click and select **Subdivide** from the Edge context menu, switch back to vertex select mode and press G to move the vertex on the target location. You can also select Subdivide as part of the Edge menu in Edit Mode **(Fig. 20).**

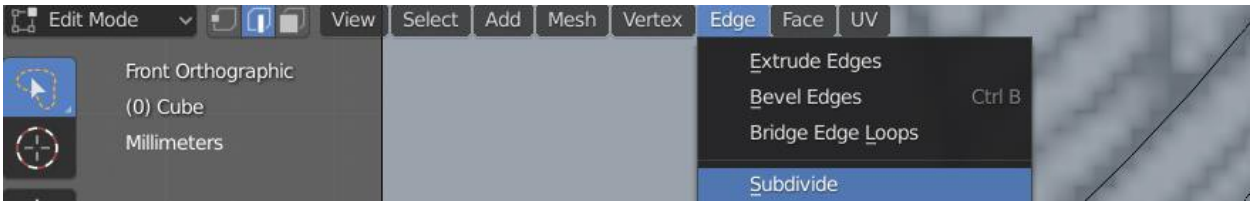

Figure 20

LATHE TECHNIQUE - CREATING THE 3D MODEL BY SPINNING IT AROUND THE Z AXIS

The word 'lathe' refers to a machine that is used in crafting of objects, in whereby the object is spun around a certain axis and gradually ground down to the desired shape. We will use the spin tool which extrudes the selected elements, rotating around a specific point and axis: The point of view will determine around which axis the extrusion spins; The position of the 3D cursor will be the center of the rotation.

1) To create a correct 3D model we first need to set the location of the **3D cursor**, as it will act as reference point for the spinning: in edit mode and with vertex select mode, select the last vertex of the profile towards the center; press SHIFT + S (snap) and select "Cursor to Selected" to snap the cursor to the vertex.
2) Although it is not necessary for the spin operation, it is good practice to maintain the **origin point** of the object close to its center. To this end, turn to object mode and under the Object menu set **Origin to 3D cursor (Fig. 21).**

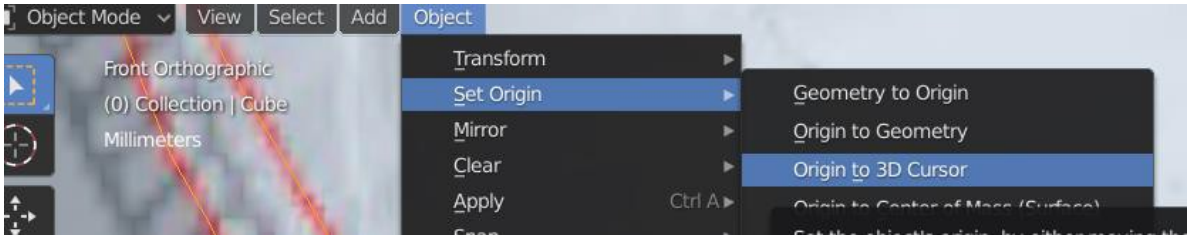

Figure 21

3) After completing this operation save your file, then choose "save as" to save it with another name. Once the spin tool is applied, it is not possible to go back to the original profile, so this helps in case you want to modify again your profile.
4) Press 7 on your numpad to enter Top Ortho view.
5) In edit mode, press A to select the entire profile.
6) Select the **Spin tool** from the Tools panel and a gizmo will appear **(Fig. 22).** Hit the + button and drag around 360°. Notice that a window appears on the left bottom of your screen where you can modify your object. Set the steps to 40 and make sure that the angle is 360°.

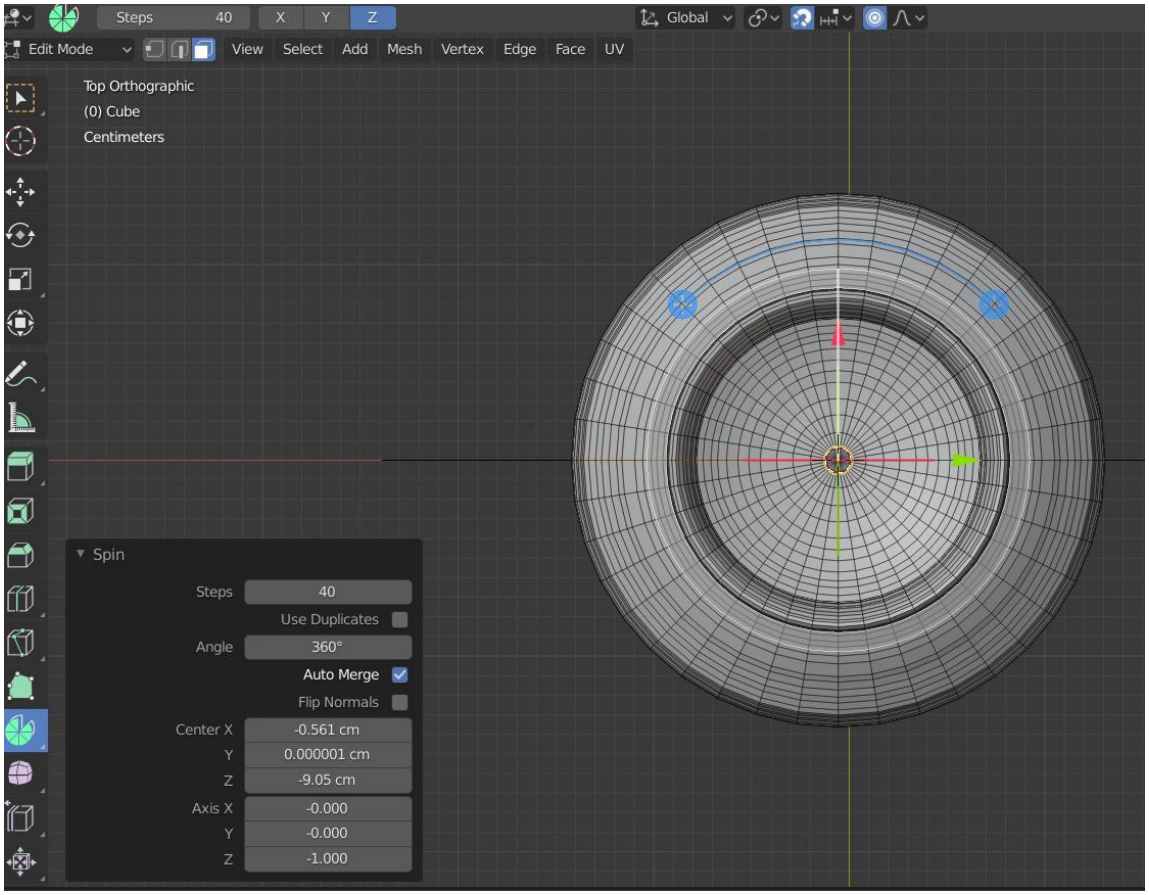

Figure 22

7) The spin operation leaves duplicate vertices along the profile at the seam. Remain in edit mode, select all the vertices and from the **Mesh Menu** choose **Clean up .** On the bar at the bottom of your screen, a message will be highlighted displaying the number of double vertices that have been removed **(Fig. 23)**.

Figure 23

8) Switch to object mode and observe the coarsely tessellated geometry of the 3D model. We are going to use a modifier to create a better approximation of the surface without increasing the polygon count: To do so, go on the properties panel and choose the **Modifiers** panel (with the screwdriver symbol). Click on **Add Modifier** and under the second column with **Generate** as header choose **Subdivision Surface** and leave the default parameters. You will notice that now the geometry is now more finely tessellated. **Apply** the modifier.

9) To further display a smoother appearance without increasing the polygon count of the object select **Shade Smooth** from the **Object menu.**

3D MODELLING THE HANDLE (optional)

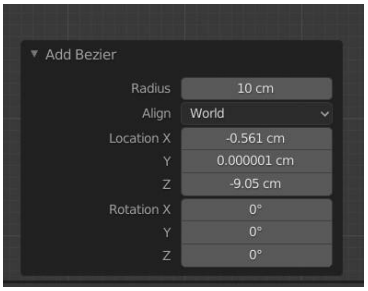

Figure 24

1) Shift + A and add a **Curve Bezier.**
2) A dialog box opens on the left bottom part of the viewport where you should set the radius at 10 cm **(Fig. 24)**.
3) Move the Bezier curve to the drawing to the position of the handle. First G+Z to elevate it and then G+X to move it to the right.
4) Numpad 7 and the top orthographic view offers more flexibility in positioning the curve. R+X to turn it to the right direction.
5) Numpad 1 and R+Y.
6) Switch to edit mode and observe the Bezier curve. The black line with the extra angled lines like centipede legs coming off it is the Bézier curve. The white or orange dots are the **control points**, with the ones in the middles of the pink handle lines defining the **endpoints** of the curve segment. You can move a selected point in the usual way, with G: note how moving an endpoint causes the curve to bend so it always connects to the endpoint. Moving just a point at the end of a control handle affects the inner part of the curve, making it bend more or less sharply away from the endpoint: try moving one of these points around, and note how the handle gets longer or shorter, and automatically rotates as necessary to remain a single straight line. Alternatively, you can select an endpoint (which selects the entire control handle, remember) and use R to rotate the handle, and S to make it longer or shorter. To add an extra point between the two curves, select the two endpoints and subdivide.
7) The curve will be extruded towards every direction, therefore we draw it in the middle of the handle profile.
8) **Find the Object Data Properties on the Properties editor (the icon is now in the shape of a curve). Under the Geometry and the Bevel tab set the Depth to 0.7. Select the upper endpoint and set the Radius to 1.500 in the Item panel (Fig. 25). Do the same with the middle endpoint until it matches the profile from the drawing.**

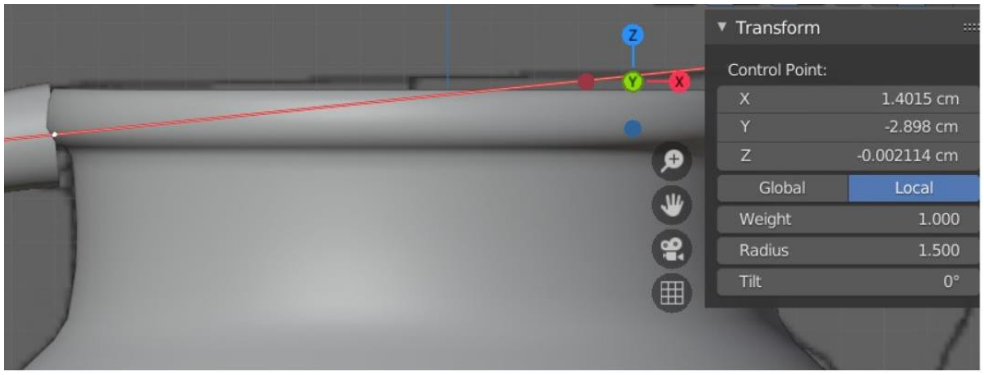

Figure 25

9) However, the handle is not cylindrical but oblate (see on the parallel drawing) with diameter of approximately 3.8 cm. From **Viewport Shading** panel click on the **Wireframe icon** (Fig. 26).

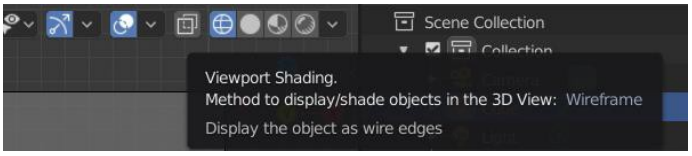

Figure 26

10) Object mode and S+Y to create the oblate form of the handle. Use the Measure tool to control the dimension of it.

11) The handle is ready but still not attached to the main vessel. Numpad 1 and G+X to move the handle further from the vessel. Select the vessel, turn to edit mode and delete the faces that the handle would be attached to (the adjoining ones) **(Fig. 27).**

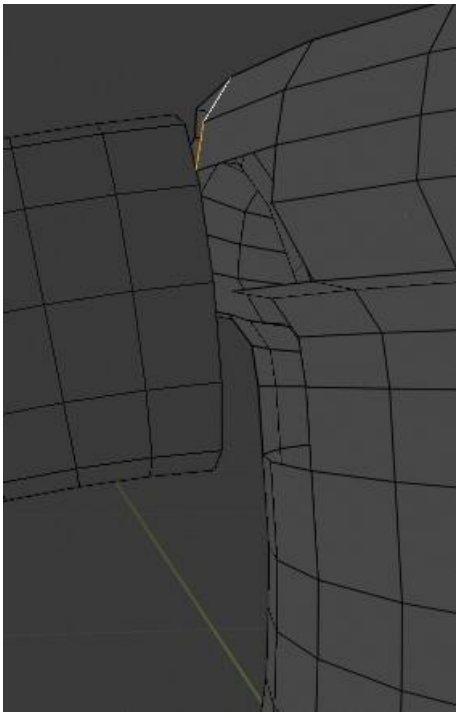

Figure 27

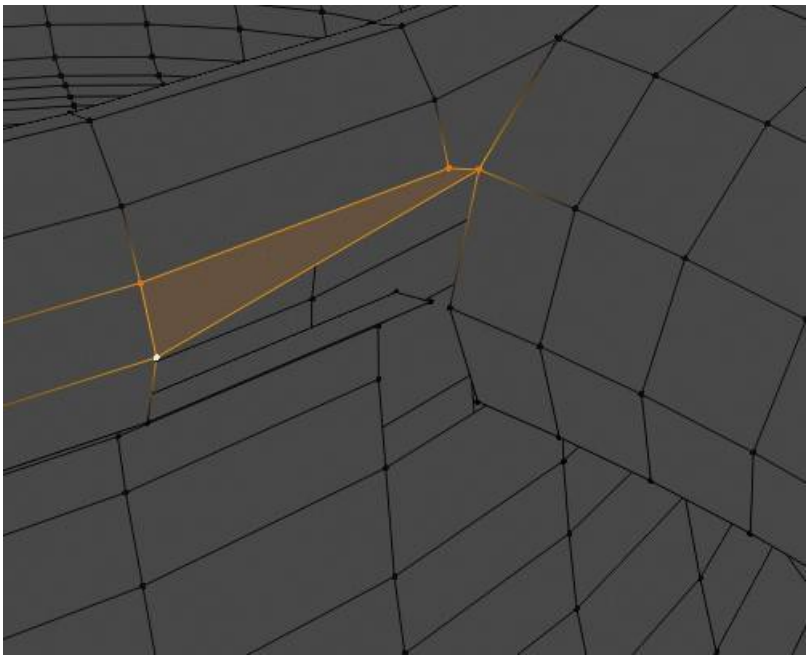

Figure 28

12) In order to join the end points of the handle to the vessel, you need to convert it to a mesh (it is still a Bezier curve). Go to object mode, and from the Object menu choose **Convert to Mesh from Curve/Meta/Surf/Text**.

13) Select both the vessel and the handle and Join them in one object (**Ctrl+J**). Return to edit mode. Select adjoining vertices and click F to fill the gap between them **(Fig. 28)** and connect the handle to the

vessel. Try to avoid forming triangles since they give a rougher and unrealistic impression. Subdivide your edges in order to have more vertices available **(this is a difficult process even for the skilled 3d modellers. The purpose of adding the creation of the handle here is to show you how a Bezier curve is used in Blender)**.

14) Switch to Top orthographic and to **Wireframe** mode and delete the right half of the object in edit mode. We do not need it. We will mirror the left part with the handle **(Fig. 29)**.

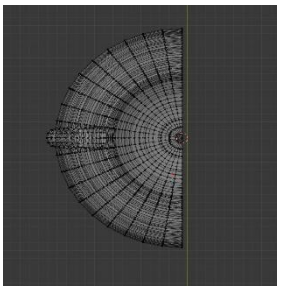

Figure 29

15) **Ctrl + A** to apply the transformations (Rotation and Scale).

16) Add the **Mirror modifier.**

17) **Apply it.**

CALCULATING THE VOLUME

1) We will use the Blender add-on 3D Print toolbox to extract these measurements. This add-on doesn't require installation but needs to be set active in the user preferences **(Fig. 30)**.

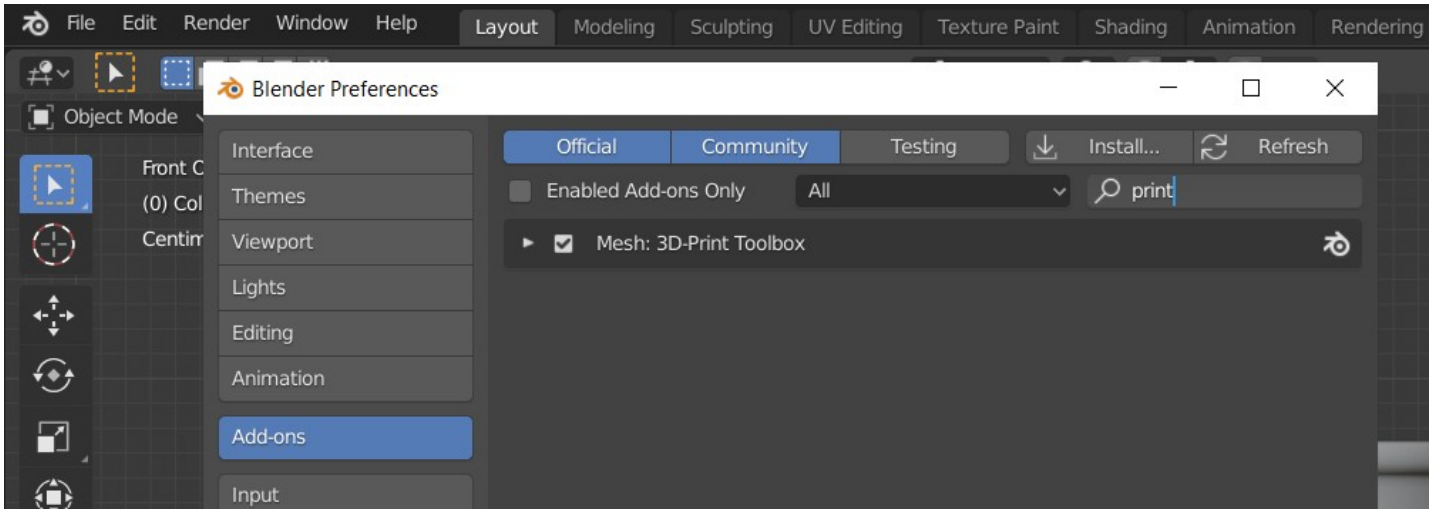

Figure 30

2) Toggle N and you will see a new tab **3D Print.**

3) Switch to edit mode.

4) To quickly select only the inner faces for the calculation: ALT+LMB (edge loop) on one edge of the inner part of the 3D model, just under the rim; Hit Spacebar and search for the **Select Loop Inner-Region.** Click and you the interior of the vessel will be selected **(Fig. 31).**

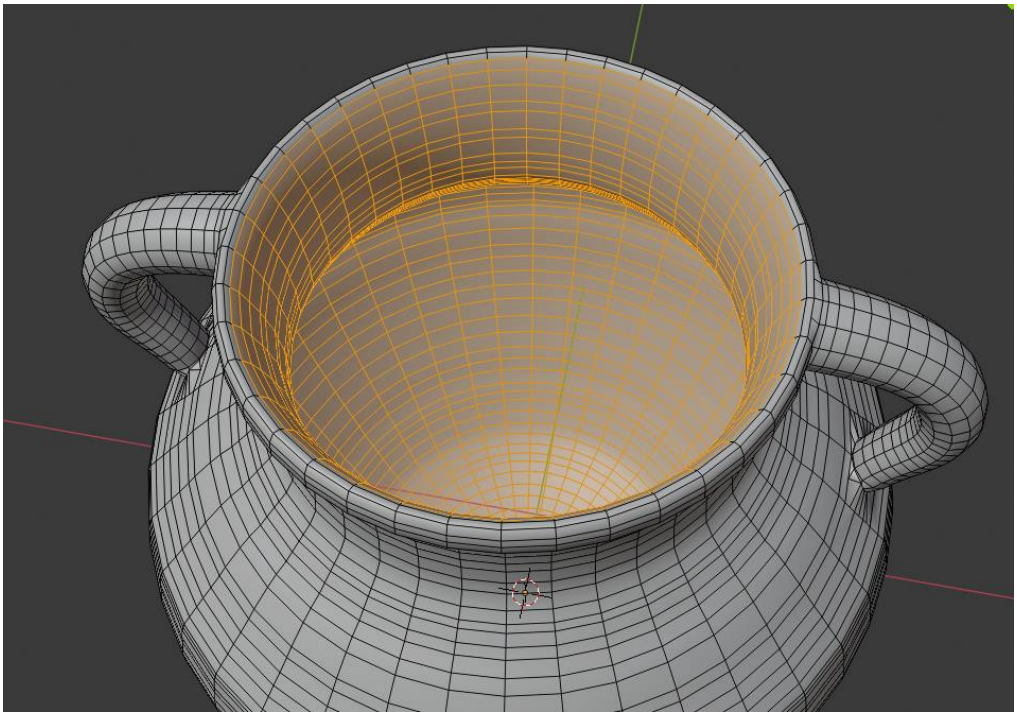

Figure 31

5) SHIFT+D to duplicate the selected faces (move your mouse to drag them to a nearby location).
6) Duplicated faces belong by default to the parent object, but we need to separate them from it in order to properly calculate the volume. To do so, press P and choose Selection to separate the selected faces from the 3D model. Note that in the layer outliner a new layer has been created (Cube.001).
7) The origin of the newly created object is however still on the same location of the parent object's origin, therefore switch to object mode, select the Cube.001 and from the Object menu choose to set the **Origin to Geometry.**
8) Switch to **Edit Mode.**
9) In order for the 3D print add-on to calculate the volume, the shape needs to be closed. To cap the selected faces: ALT+LMB (edge loop) on one segment of the outer most edge and then press F to cap it.
10) Switch to object mode.
11) Press A to select all the faces and press "**volume**" under the 3D printing tab to calculate the volume **(Fig. 32)**. When this tool is used for archaeological analysis, make always sure to check the results against a control object in your dataset to monitor the accuracy of the calculation.

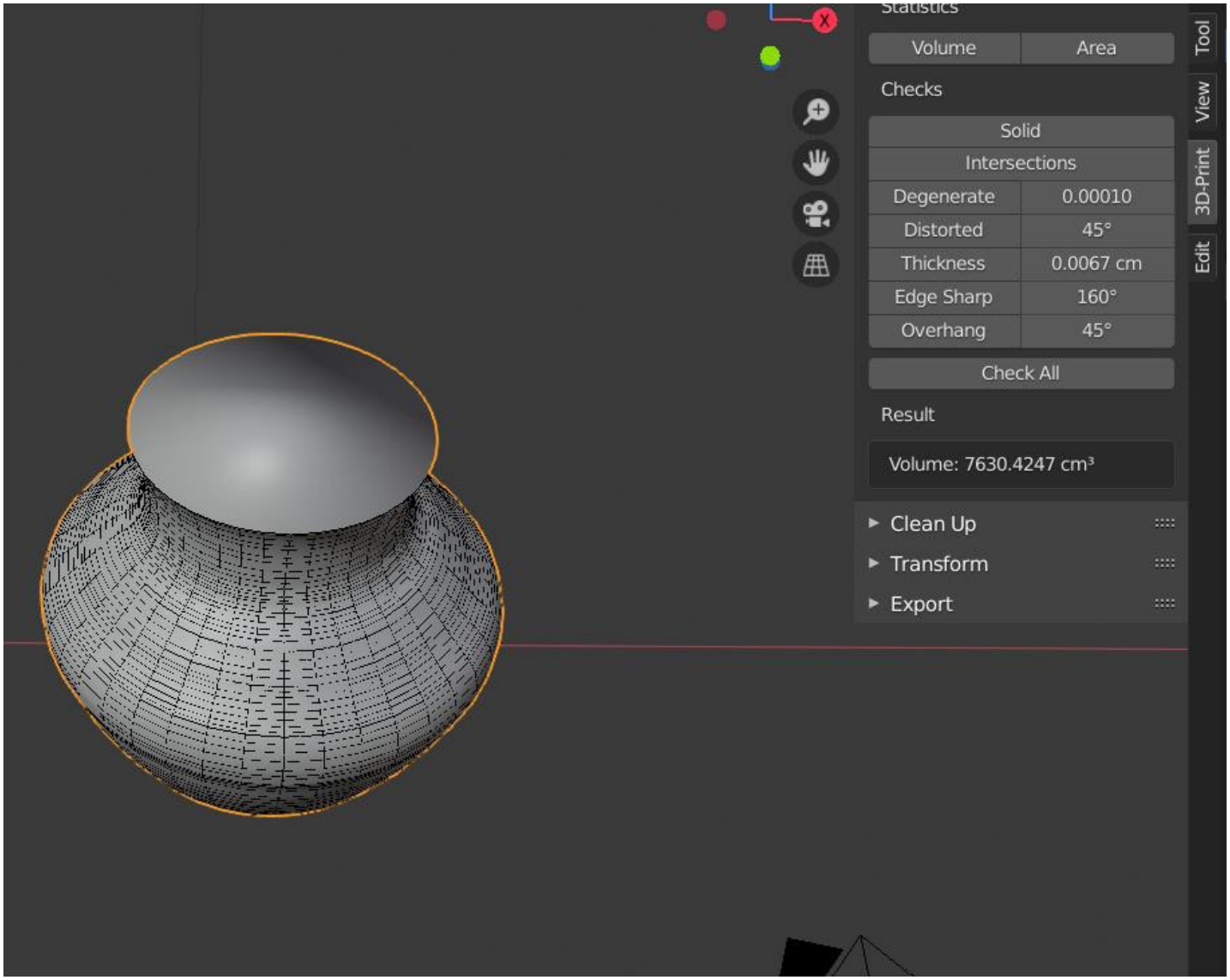
Statistics
Volume
Area
Checks
Solid
Intersections
Degenerate
0.00010
Distorted
45°
Thickness
0.0067 cm
Edge Sharp
160°
Overhang
45°
Check All
Result
Volume: 7630.4247 cm³
Clean Up
Transform
Export
Tool
View
3D-Print
Edit

Figure 32

Food for Thought

Several decisions had to be taken in order to complete the reconstruction such as which profile (left or right) should be digitized or to which degree the scale was accurate. Many decisions that could affect the final result could have been made during the data collection as well. It is always important to develop our reasoning behind those choices and minimize the level of uncertainty, especially when our project is used for research.