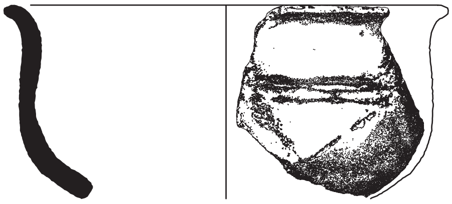
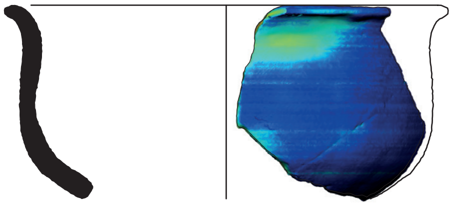
DACORD

Computer-Assisted Drawing of Archaeological Pottery

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Computer-Assisted Drawing of Archaeological Pottery

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Installation

1. Support program installation

Download and install the following applications, depending on your operational system, from official developer web sites:

- ‘R program’ (https://www.r-project.org/)
- ‘RStudio’ (https://www.rstudio.com/)
- ‘Meshlab’ (http://meshlab.sourceforge.net/)

2. Application installation

Download and unpack the DACORD.zip file. Copy the unpacked DACORD folder on your computer (for example C:/DACORD).

3. Installing packages

Open ‘RStudio’ program in administrator mode. DACORD uses various libraries for computation and visualisation. In further steps, all necessary libraries must be installed on your computer. Two library installation options are possible:

a) If you have internet access, you can simply copy the following code lines to the R console and press enter (Fig. 1).

```
install.packages(c("alphahull", "conicfit", "cwhmisc", "doParallel", "fit.
models", "foreach", "igraph", "iterators", "MASS", "mco", "mesheR",
"Morpho", "optimx", "parallel", "plotrix", "png", "pracma", "rgl",
"robust", "robustbase", "rrcov", "Rvcg", "SDMTools", "shiny", "sp"))
```

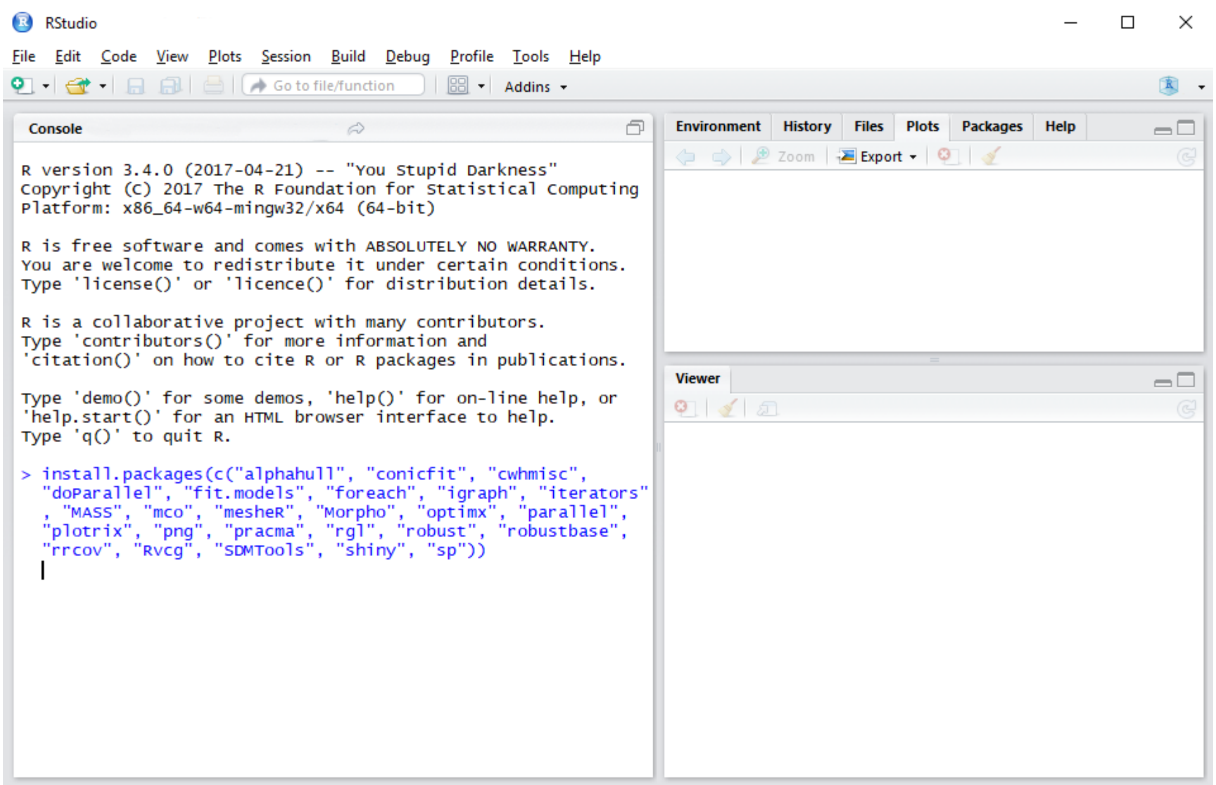

Fig. 1. Package installation with intenet access.

b) Otherwise you can install packages directly from the 'lib' folder. In that case, select and paste the following code to the Rconsole (Fig. 2):

```
setwd("C:/DACORD")
pac <- list.files(paste(getwd(),"/lib/",sep="")); for(i in 1:length(pac)){
install.packages(paste(getwd(),"/lib/",pac[i],sep=""), repos = NULL, type =
"win.binary") }
```

Note that instead of `C:/DACORD` in the code, you can specify the path to the folder containing the DACORD application.

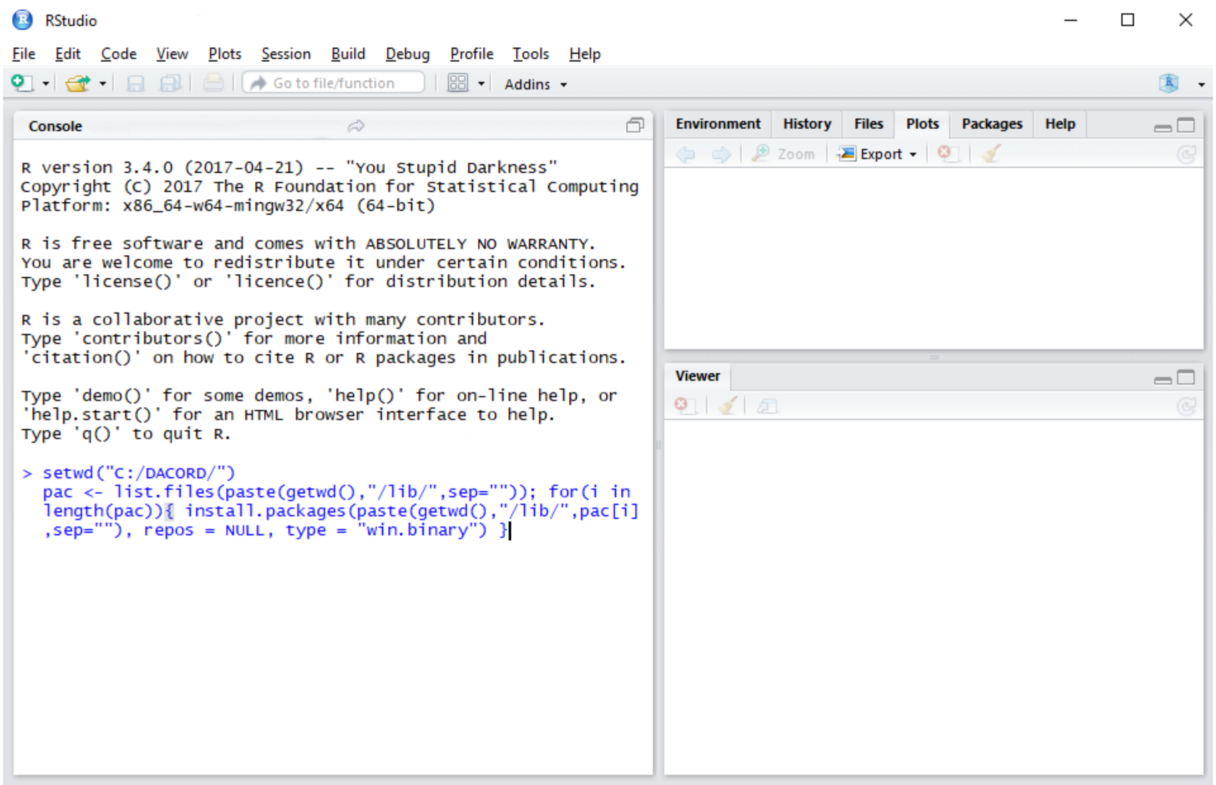

Fig. 2. Package installation from 'lib' folder.

4. Setting PATHs in environment variables

DACORD requires access to several applications (like Rscript.exe or Meshscript.exe), allowing faster calculations of several functions. The PATH to these applications must be defined as environment variables in MS Windows (Fig. 3).

In MS Windows 10, the path to these applications is defined as follows:
a) Access the System window of your computer. Click Advanced system settings and Environment variables...
b) In System variables list Path and click Edit
c) Click New and insert the path to the folder containing the Rscript.exe file (by default it should be located in C:\Program Files\R\R-{version}\bin\)
d) Click New again and insert the path to the folder containing the meshlabserver.exe file (by default it should be located in C:\Program Files\VCG\MeshLab\)
e) Click OK

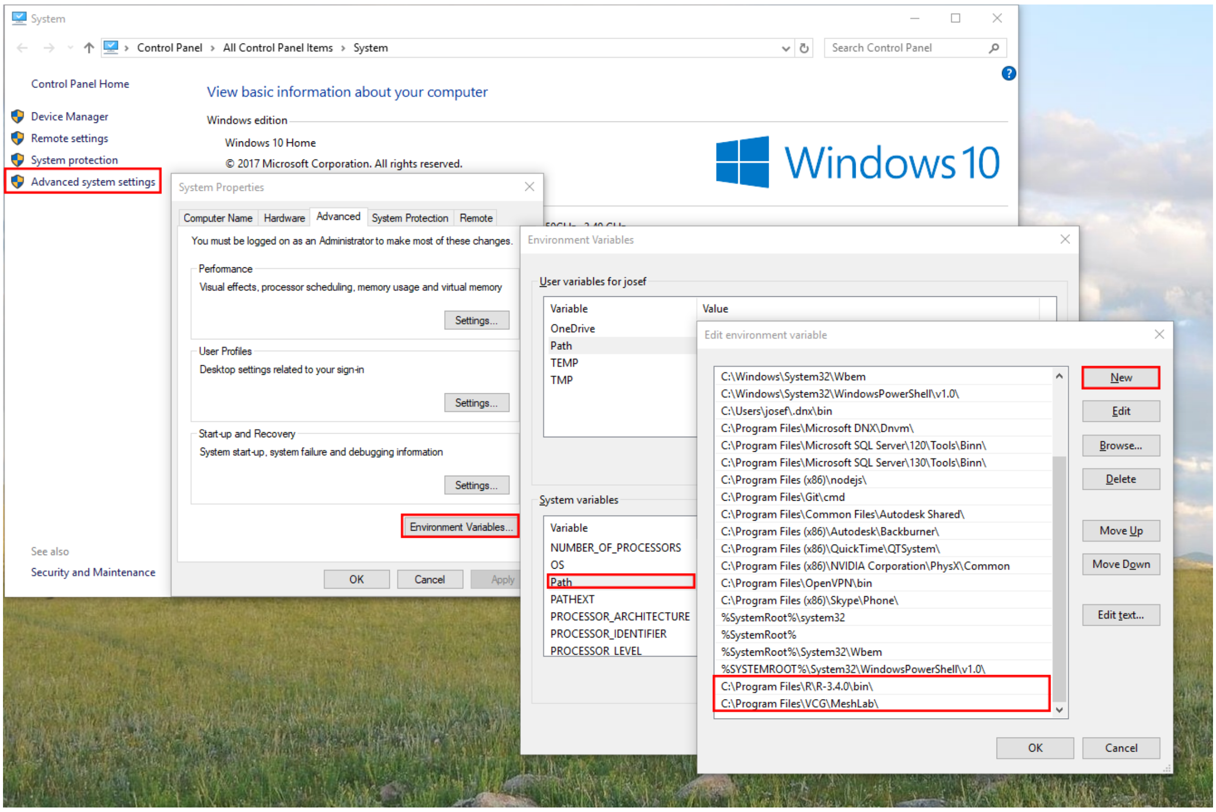

Fig. 3. Setting PATHs in environment variables.

5. Preparing and running the DACORD application

The path to the DACORD application must also be defined in its source code. To do so, open both _support_ME.R and server.R files in the RStudio program (Fig. 4; Fig. 5). Specify the path to your DACORD application folder by replacing the code at the beginning of both files by:

```
WD <- c("C:/DACORD")
```

Note that instead of `C:/DACORD` in the code, you can specify the path to the folder containing the DACORD application.

The DACORD application is run by clicking on the Run App icon in the RStudio panel (Fig. 5; Fig. 6). The graphical layout of the application can be adjusted at the begining of the ui.R file, depending on the screen resolution (Fig. 7).

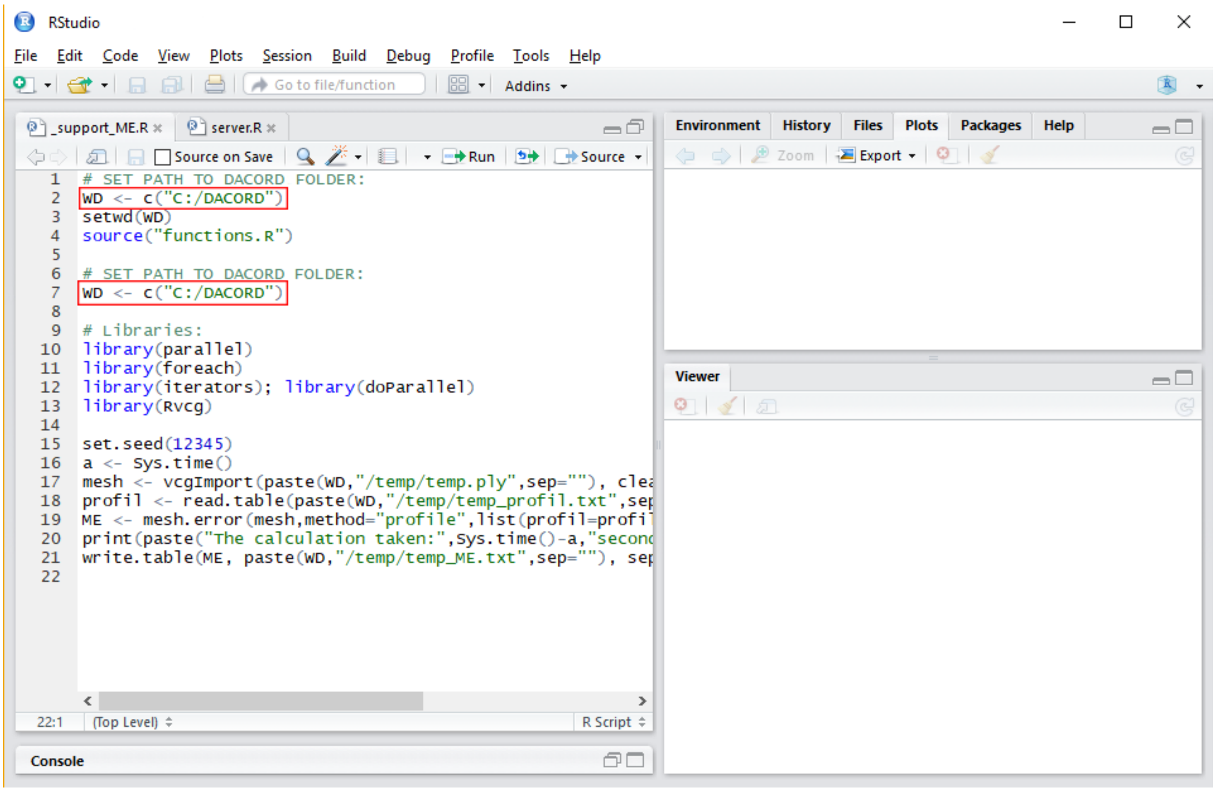

Fig. 4. Setting the path in the source code (_support_ME.R).

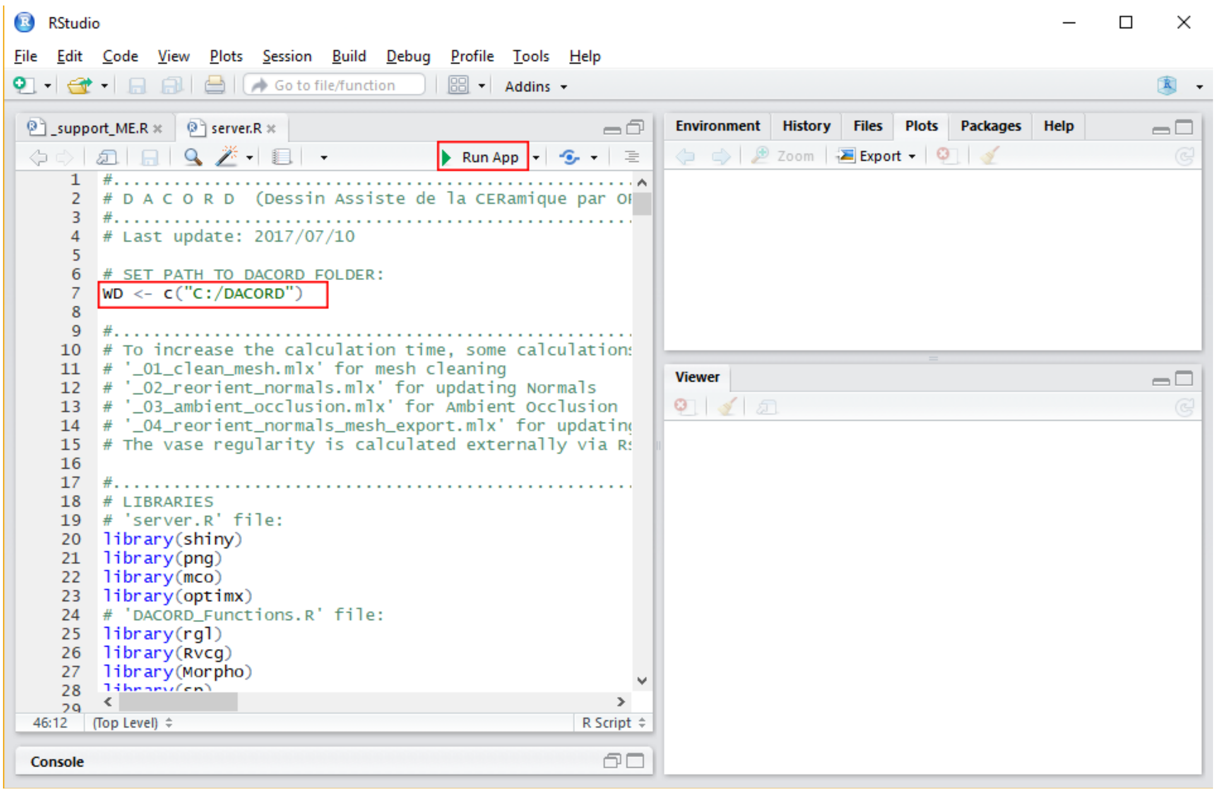

Fig. 5. Setting the path in the source code (server.R) and running the application.

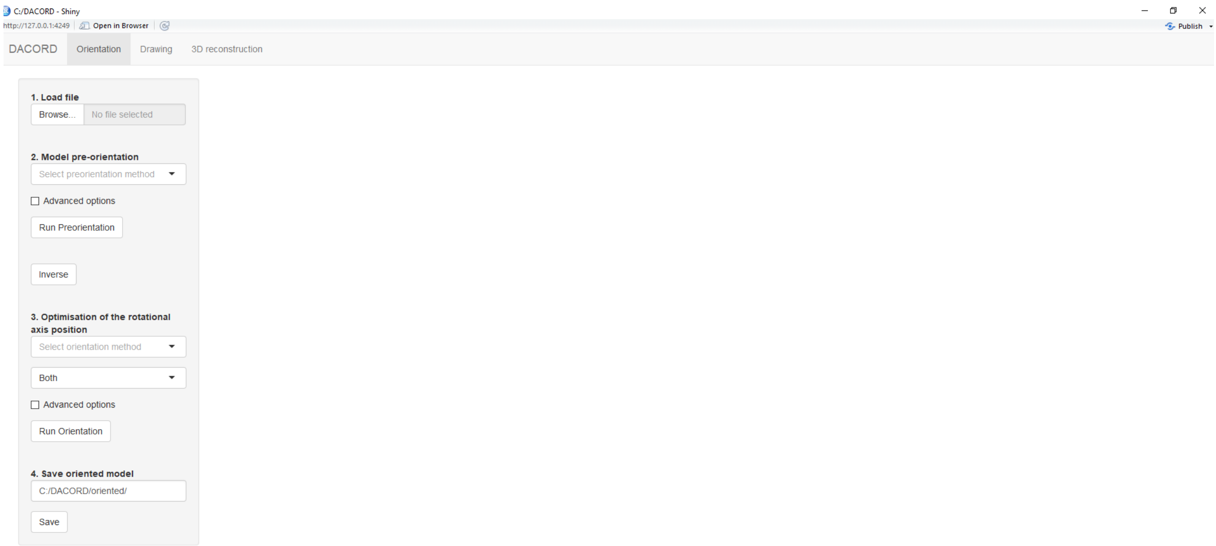

Fig. 6. The DACCORD application.

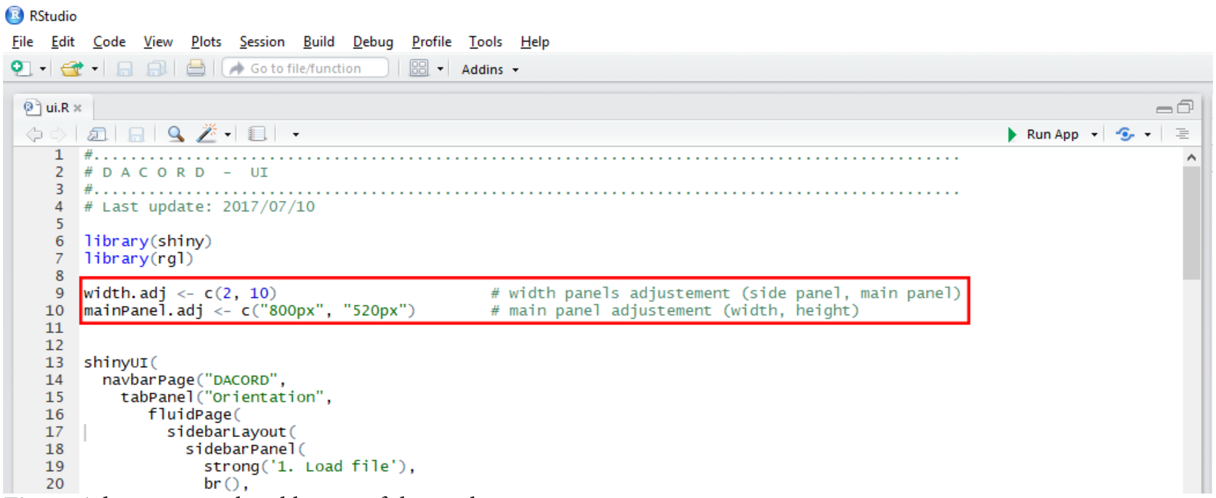

Fig. 7. Adjusting graphical layout of the application.

Manual

The 3D model of the pottery fragment to be oriented and drawn by the system can be obtained by any available 3D acquisition method (3D scanner, CT scan, photogrammetry, etc.). However, the accuracy of the results is highly dependent on the quality of the model. For the best possible output, models should be watertight, properly cleaned (i.e. without holes, non-manifold or duplicated faces) and all vector normals should be correctly oriented. Several examples of 3D models are provided in the 'examples' folder.

The DACORD program aims *(i)* to find the optimal rotation axis of the 3D pottery models, *(ii)* to produce archaeological drawings, and *(iii)* to create 3D reconstructions of the preserved vessel fragments. The application therefore contains three panels: Orientation, Drawing and 3D reconstruction, each one dedicated to the corresponding task (Fig. 6).

1. Orientation

The Orientation workflow is quite straightforward and can be separated into four consecutive steps:

1.1. Load file

The Browse button serves to load the unoriented mesh file. For the moment, the system supports only PLY 3D model format (both ASCI and Binary modes). By default, the model size is limited to 200 MB. However, to speed up calculation time, it is better to decimate the model to 150 000 vertices, corresponding to 8 MB.
Once the model is loaded, the greyscale unoriented decimated pottery model is opened in the upper part of the screen. Note that the model can be rotated by pressing the left mouse button, and zoomed by the scroll wheel or by the right mouse button.

1.2. Model pre-orientation

Model pre-orientation serves to provide an initial position for the rotation axis of the model. Two options are available: the fragment can be pre-oriented manually or automatically. The method selected is validated by pressing the Run Pre-orientation button.

The Manual option is preferred if the correct position of the fragment is obvious, for example when the fragment contains the rim or base, or has horizontal decoration. If the Manual method is selected, a new digitising window is opened, and the user has to define three points lying within the same horizontal plane (e.g. three points on the rim or on the horizontal decoration). Each point can be located on the model by a right mouse click, followed by pressing the Escape keyboard button. Note that when a point is placed, a new detailed model view appears, allowing more precise point positioning. Already positioned points can be modified by a right mouse click. Once three points have been correctly placed, the pre-orientation process is started by closing the digitising window.

The Automatic orientation option estimates the rotation axis, based on the geometric properties of the pottery model. The best results are obtained for fragments without surfaces whose normals are (nearly) parallel to the rotation axis.
The calculation parameters of model pre-orientation can be fine-tuned in Advanced options:
Initial decimation indicates the number of vertices used for calculation (5000 vertices, by default). Lower values may speed up calculation but may lead to a lower quantity of points needed for final rotation axis estimation in the next step. Higher values increase rotation axis precision, but also calculation time.

Smoothing iterations allows preliminary model smoothing (5 iterations, by default). Lower values are suitable for fragments with nearly flat surfaces; higher values may lead to model oversmoothing.
p-value extraction (manual preorientation) indicates the probability threshold required to remove unwanted features, i.e. mainly vessel fractures (0.95, by default).
Percentile for extraction (automatic preorientation) indicates the vessel surface portion, supposed to contain significant information for rotation axis estimation (0.50, by default).
Visualisation allows the calculation process to be monitored, but significantly slows calculation (unchecked, by default).

The pre-orientation process is started by pressing the Run Pre-orientation button. Calculation progress is indicated in a bar in the lower part of the screen. Once this step is complete, the pre-oriented model with its rotation axis is shown in 3D and profile projection. The inner (red) and outer (blue) pottery model surfaces are plotted; they contain pertinent information about the rotation axis.
Note that the pre-oriented model may be plotted upside down. In that case, the fragment can be repositioned by pressing the Inverse button.

1.3. Optimisation of the rotation axis position

Once the initial position of the rotation axis has been estimated, seven different methods can be used to improve pottery fragment orientation:
(0) None
(1a) Horizontal circle adjustment using radius (4DDL)
(1b) Horizontal circle adjustment using radius (3DDL)
(2) Horizontal circle adjustment using multi-criteria approach
(3a) Vertical profile superposition
(3b) Vertical profile curve fitting
(4a) Tangent plane to rim
(4b) Tangent plane to base

The choice of the most suitable method depends on the fragment part (rim, body, or base), the geometric properties of the model, and the feature the user chooses to focus on.
For most methods (method 1-3), it is possible to define the fragment part(s) (Outer (Blue), Inner (Red) or Both) on which the final alignment will be calculated. This option is included because some methods can only treat one surface of the model, but also because the artefact can be more regular on the outer surface than on the inner one, for example.
Note that if the pre-oriented model position is satisfactory, the option (0) None can be selected as the final model orientation.

The calculation parameters used in model orientation can be fine-tuned in Advanced options (numbers in parentheses correspond to orientation methods):
Number of sections (1-3a, 4) indicates the number of horizontal or vertical sections (12, by default). Higher values increase accuracy but slow calculation. When the value 0 is chosen, the number is set to the maximum possible number of sections given by the model resolution.
Polynomial order (3b) indicates the polynomial order (12, by default). Low and high values lead to erroneous results.
Search parameter limits (2) indicates the limits of two rotation parameters (phi and theta) in Pareto front optimisation (+-10 degrees, by default).
Search generations (2) indicates the generation size used in Pareto front optimisation calculation (20, by default).
Search popsize (2) indicates the population size used in Pareto front optimisation calculation (20, by default).

Decimation (4) indicates the number of vertices used for calculation (2000 vertices, by default). Higher values increase rotation axis precision, but also calculation time.
Z-threshold (4a, 4b) indicates the threshold distance (in mm) defining the pottery rim or base (1 mm, by default).
Visualisation allows the calculation process to be monitored, but significantly slows calculation (unchecked, by default).

The orientation process is started by pressing the Run Orientation button.
Once the orientation is complete, the oriented model with its rotation axis is visualised in 3D and in profile projection, allowing visual inspection of alignment quality.
Note that if the (2) Horizontal circle adjustment using multi-criteria approach was selected in orientation, two additional Pareto front graphs are plotted. The first shows the Objective space, showing the results of the best Pareto outputs, the second the Parameter space, indicating the corresponding best model rotation parameters (phi and theta). The user can obtain the desired output by adjusting the Number of best solutions (visualised as blue dots in the graphics), indicating the number of best Pareto solutions used for final alignment.

1.4. Save oriented model

The final oriented model can be exported in PLY format in the folder indicated in the Save oriented model selection by pressing the Save button.

2. Drawing

The model is now prepared for the final drawing stage. The system is in conformity with the majority of norms and standards used in traditional archaeological pottery illustration. As with any digital image computer editor, it uses the superimposition of different layers, each one containing either vector (profile or decoration) or raster (fragment surface) elements.

2.1. Load file

The Browse button serves to load the oriented mesh file. See section **1.1. Load file** for more details.
Once loaded, the oriented model with its rotation axis is visualised in the profile projection.

2.2. Profile type selection

The drawing process starts with the definition of the position of the profile section used in the final illustration. The user can choose between four different profile representations:
Whole envelope profile
In the middle of the fragment
Longest preserved profile
Arbitrarily selected profile
Profile selection needs to be validated by pressing the Get profile button.
By choosing Arbitrarily selected profile, a new digitising window is opened and the user must define the selected profile by clicking the right mouse button anywhere on the fragment.
Once calculated, the profile with its rotation axis is plotted in the upper part of the screen. The blue outline corresponds to the outer part of the model, while the red outline corresponds to the inner part of the model. The user can readjust both parts by a left mouse double-click on the graphic.
The prolongations of Missing profile parts can be set by clicking the left mouse button on pairs of points on the graphic. The last line drawn can be erased by clicking the Erase last line button.

2.3. Drawing type selection

The system supports six major modes of archaeological illustration:
(1) Linear drawing - produces a linear archaeological illustration of the fragment;
(2) Photographic drawing - represents the fragment in colour or greyscale;
(3) Shaded drawing (DL) - highlights fragment shading using directional lighting;
(4) Shaded drawing (AO) - highlights fragment shading using ambient occlusion;
(5) Shaded drawing (combined) - highlights fragment shading using both directional lighting and ambient occlusion;
(6) Pottery regularity - highlights fragment regularities and visually expresses the quality of rotation axis estimation.
The selected illustration mode can be visualised by pressing the Draw button. The image obtained can be customised by adding various features.

Additional features available for all drawing types (i.e. 1-6):
Rim adds a rim line.
Base adds a base line.
Missing profile parts adds missing profile parts if defined in Profile type selection (see section **2.2. Profile type selection** for more details).
Lines adds supplementary horizontal lines. Their position is set by clicking on the graphic. The last line drawn can be erased by clicking the Back (Erase last line) button.
Scale adds a scale (a 5 cm black scale is set, by default)
Circle sector preservation indicator adds a circle sector preservation indicator (in degrees).
Rim diameter adds a rim diameter.

Measurements (1) adds measurements. Measurements are given by pairs of points set by a left mouse button double-click on the graphic. The last point drawn can be erased by clicking the Back (Erase last point) button.
Volume (1) adds vessel volume estimation (in L) given by Boundary values.

Mask (2-6) hides the part of the fragment left of the rotation axis.

Photographic mode (2) indicates if the fragment is drawn in Colour mode or Greyscale mode (Colour mode, by default).
Additional light (2) illuminates the fragment.

Advanced light (2-3, 5) sets the light position in relation to the fragment. Values are expressed in polar coordinates (Latitude, Longitude, and Distance).

Fragment position (2-6) can be set by horizontal Translation and by Rotation of the fragment around the rotation axis. To speed up the drawing process, the fragment position should be initially set in Photographic mode (2).

Advanced shading (3-5) defines the shading (in the form of points) in the illustration. Point values are represented in the histogram(s).
Filter automatically adjusts points in the illustration (unchecked, by default).
Percentiles serves to visualise points in the histogram(s). Only points falling within the selected interval are shown in the histogram.
Boundaries 1-3 serves to set the boundaries of points visible in pottery illustration.
Percentage indicates the quantity of points to be drawn in the illustration.

Select drawing quality method (6) indicates if the distance of the fragment is calculated According to the rotation axis or According to ideal vessel.

2.4. Save current drawing

The drawing currently visualised can be saved any time by pressing the Save button. The illustration file will be saved in the folder indicated in the Save current drawing selection.

3. 3D reconstruction

The system reconstructs and exports the 3D model of the preserved part of the vessel in PLY format.

3.1. Load file

The Browse button serves to load the oriented mesh file. See section **1.1. Load file** for more details.
Once loaded, the oriented model with its rotation axis is visualised in the profile projection.

3.2. Profile type selection

The reconstruction starts with the definition of the position of the profile section used for 3D reconstruction. See section **2.2. Profile type selection** for more details.

3.3. 3D reconstruction selection

The system supports four modes of model reconstruction visualisation:
(1) Plastic model
(2) Sliced model
(3) Wireframe model
(4) Pointcloud
The selected 3D reconstruction is visualised by pressing the Reconstruct button. The original pottery fragment can be incorporated into the scene by checking the Add model box.

3.4. Save 3D reconstruction

The 3D reconstruction model can be exported to the folder indicated in the Save 3D reconstruction selection, in PLY (for 1, 3) or TXT format (for 2 and 4), by pressing the Save button.