Photogrammetry, GIS and Remote Sensing Techniques applied to the Roman Villa of Aiano-Torraccia di Chiusi (Siena, Italy)

Foreword

The site of the villa at Aiano-Torraccia di Chiusi[1] is located in the municipal district of San Gimignano (Siena, Italy) in the valley of the torrent Foci. In spite of the fact that the site was discovered some time ago, it had never been studied before the summer of 2005, when the Université catholique de Louvain (UCL, Belgium) decided to start a project in order to systematically explore the site over several years.

This decision was taken because of the interesting archeological finds from the site, and in particular because it was considered necessary to re-examine – possibly on the basis of new data – the numerous questions, on the population, the economy, the rural environment, etc. of the Valdelsa area (the valley of the river Elsa) in the Roman period. The period considered is quite wide, as it extends from the first phases of Romanization, to Late Antiquity and the Early Middle Ages (1st century B.C.-8th century A.D.).

Available archaeological data

During the first four excavation campaigns, 1000 m^2 were investigated out of the one hectare which is thought to represent the surface of the villa.

Up to now the excavations have brought to light an important part of the villa, probably an area of *otium* (living room), characterized by a wide triangular room, with corners in the shape of circular exedras. The discovery of this area, of which ca. 100 m^2 have excavated so far, revealed the residential function of the place and the high degree of cultural and economic development of its inhabitants. Moreover, the study of the different archeological findings showed that, in the area already excavated, there has been a succession of various building methods and life styles, which transformed the aspect, the plan and the functions of the villa (Fig. 1).

Photogrammetry

For the present work, concerning collection of images and data setting, we used a consumer digital camera (Nikon Coolpix P3) and a total topographic station with reflecting prism (Topcon GTS-702). For the photogrammetric elaboration and the classification of images we employed the elaboration suite LEICA ERDAS

[1] http://www.villaromaine-torracciadichiusi.be/.

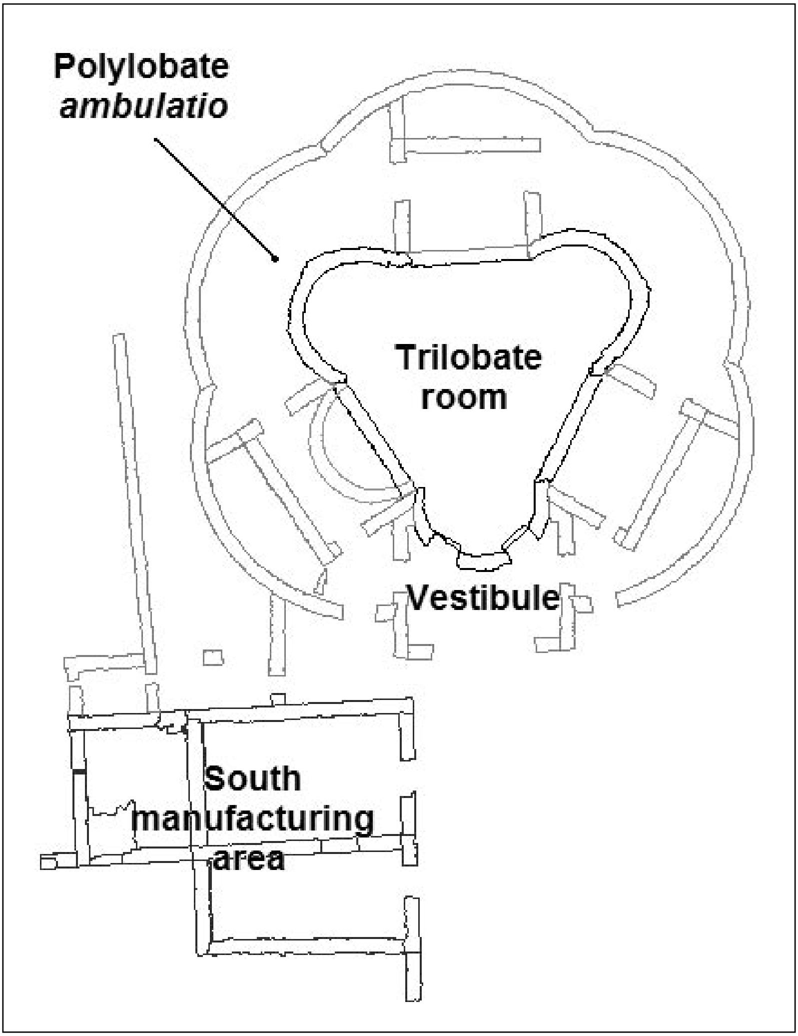

Fig. 1 – Plan of the Roman villa at the end of the fourth excavation campaign (1000 m²), summer 2008.

IMAGINE 9.1 with the extension LEICA PHOTOGRAMMETRY SUITE, and for digitization and for the construction of a vector database we used the software ARCGIS 9.2.

The operative sequence of photogrammetric research consists of some fundamental passages. Firstly, the right choice is important of both the frames of what will become the stereoscopic block, and the Internal Orientation of the camera. In this case the use of non-metric cameras allows the inclusion of only some parameters related to optical geometry (focal length and pixel size). Moreover the projection of points on the ground must be specified and this represents the most essential point of the work[2]. In this case the stereographic projection was taken as the proper one. Secondly we tried to establish a connection between the frame and a suitable ground reference system. To do this, the Ground Control Points (GCP), picked with the total station, were collimated by inserting coordinates x, y and z. In this way the points are kept in a correct spatial relationship, allowing thus the creation of the so-called stereo pair.

Further, it is also useful to insert check points in order to reduce the RMSE[3]. A further improvement is given by the inclusion of a large number of tie points. These points are collimated like GCP, but the information on the 3 coordinates is not available. They establish an objective relationship above the corresponding points on the 2 photos. The inclusion of tie points follows the entry of other automatic tie points, but the result does not improve and, in one of the considered cases (small ditch), we identified a sort of clustering. In different areas the automatic algorithms positioned the points close to other ones already manually collimated ones. Once included the control points and the manual and automatic tie points, we calculated the triangulation which established the mathematical relationship between the images building the block file and the orientation information already included. The two cases of study are presented below.

The ditch

DTM and orthophoto

The aerial triangulation process of the small ditch was obtained by the RMSE of 6.6 units, but it must be stressed that the rotation angles of the base of the frame collection, ω (roll), φ (pitching) e κ (drift), is limited if we consider the initial condition of release of photos.

We passed then to the creation of the Digital Terrain Model (DTM) of the area taken into consideration. The mainly automatic extraction process could be carried out without any problems. A medium-high quality DTM was obtained and, during the elaboration, was created also a raster file, showing the different chromatism which displays the quality of the produced DTM.

Whatever method we choose, we can see that the less accurate areas of extraction and creation of DTM are those close to the edges of the small ditch. In fact, the lack of ground point and the almost vertical abutments of the structure do not allow an effective documentation, i.e. it is as if part of a photo were missing. The stretching of pixels constituting the orthophoto, visible in these points, is the con-

[2] The term stereographic projection identifies – in geometry and cartography – the projection of points on the surface of a sphere from a point N of the sphere (often called the North pole of the sphere) over a plan – usually the equatorial plan – or on the tangent plan of a point called S, South pole (to antipodal N).

[3] R*oot mean squared error* between the real position of the object and the one collimated on the photo.

sequence of shootings in areas with many *breaklines* and it produces an irregular ground surface. The next step was the correction of DTM points in places where quarrying was more difficult. It is quite obvious that areas, in which there is not a good interpretation by the algorithm of automatic quarrying, are difficult to understand also for the operator. As the next step, a new punctual feature was created by using the Stereo Analyst of Leica Erdas LPS. We tried to put in, through the stereoscopic view, as many points as possible in areas of minor detail. After that, the monographs of the points were included among the parameters necessary to the extraction of a new DTM. However, at an immediate autoptical examination, the results did not seem to improve the situation. Therefore we moved on from the results of DTM and the orthophoto of the small ditch, to the video-digitalizing by means of the Stereo Analyst module.

Before drawing, we estimated the characteristics of the area to be tested, and discovered that not only the earth matrix but also a quantity of bricks and travertine blocks had been widely used in the building of the villa. Indeed, the abutments of the small ditch consist of bricks vertically placed and leaning against the store walls, which belong to places close to the settlements. The conclusion is that it is correct to underline the building materials because they are essential. Therefore two linear features called "bricks" were created.

The digitalizing process evidenced some difficulties in the photogrammetrical elaboration in the particular situation of the small ditch. The tested stereo-pair was affected by problems, already noticed in the creation of block file, and these problems influenced the next stages of the process. The photographic collection carried out with non-metric and non calibrated camera do not have a high precision. The use of a "bar" built and improved during the plotting allowed a reduction of the rotation angle, but not the total elimination of errors. Further, the ground collimated points for this stereo-pair were of a lower number and the reduced "height of flight"[4] and the particularly uneven ground of an area with vertical and sub-vertical face, but irregular in many points, would require an overlap with very high covering of 80% or more. Regrettably the highest possible percentage of overlap we can have is between 50% and 60%, because of the uncertain situation and the short period of work. This value is acceptable[5] but not sufficient to allow a complete superimposition of the details of the photos. In some cases, and even in the centre of the stereo-pair close to the most of the more uneven area, there are elements, which are not perfectly visible in both photos. With proper digitalizing, the central part of the photo should be evidenced, where the document structure is placed and where the most interesting archaeological characteristics are. Here,

[4] The process for frame collecting used here can be joined with the one of aerial photogrammetry even on land, i.e. from top to bottom, without control by the employed methods.

[5] In theory, the covering of "standard" aerial photos would be 60%. In rough areas a higher overlap, of around 80%, is recommended to keep the details of the photographed area. In these cases, a pattern of flight which follows the relief and the valley and avoids to intercept perpendiculars is adopted, so as not to create stereoscopies where "some" of the elements included in one of the two frames are not present in the other.

more than anywhere else, there are some visible elements of bricks and travertine, free of the earth which covers them, and we tried to draw them by underlining the exposed rim. The linear drawing so digitalized, can also be seen as tridimensional thanks to the visualization software Arcscene of ArcGIS.

The geodatabase

The first aim of the video digitalizing was to create a vector database from which to obtain a detailed plan of this excavation area. After creating the feature and vectorizing the outline of the relevant elements, the final file is saved as shape, i.e. in one of the formats of ArcGIS. The initial files are presented as closed polygons. The correct creation of a database required the passage to polygons. The followed procedure was to create a Personal Geodatabase with ArcCatalog, including dataset in which were inserted the linear shape and a new punctual shape created *ad hoc*. The latter is used to "validate" the polygons obtained from the polylines through opportune steps carried out with the software GIS.

In the geodatabase the special domains should be edited. In this case we chose a domain called "class" of coded values by type to which two values are attributed: 1 for the bricks and 2 for the travertine. The polygonal shape obtained is related to the domain of geodatabase through the "fields" of the database. In fact it includes a new field, called "classification", which is the first which had been created as reference domain (Figs. 2 and 3).

The polygons are then assigned to the correct class they belong to, by using ArcMap, and by asking the vector file to show the wording "bricks" or "travertine" among the information linked to the file.

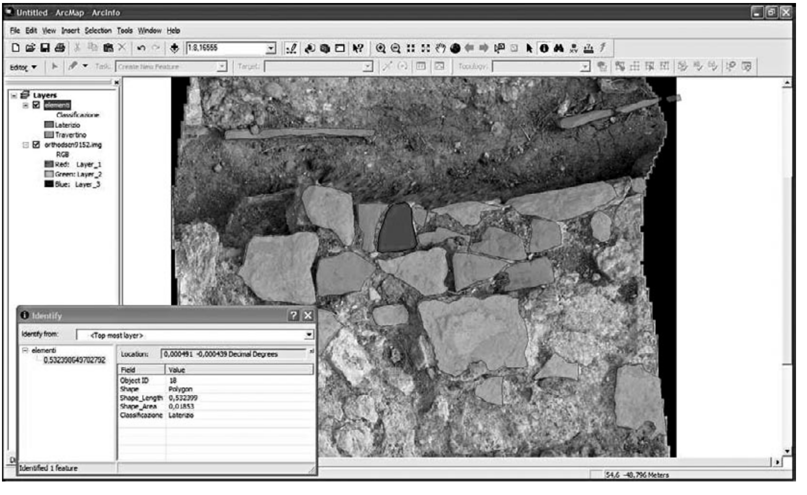

Fig. 2 –

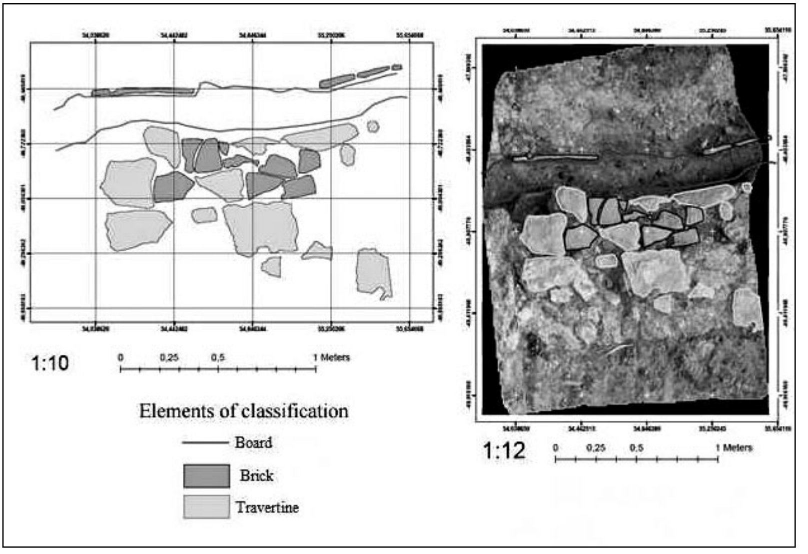

Fig. 3 – Aiano - Torraccia di Chiusi: classification of building materials.

Surface analysis

After creating the DTM, the orthophoto and the database, we tried to carry out some analysis of real surface of major dimensions. It has to be underlined that it is also possible to apply these analyses also on objects of smaller size, like for example the small ditch discussed above. Through the module 3D Analyst of ArcGIS we are able to obtain some thematic images of the slope and the depth at different points of the tested structure. The data are prepared in this way: the elevation image, represented by a raster colour-scale painting, is replaced from the DTM to the surface TIN (Triangular Irregular Network) composed by irregular triangles, linked to each other, in order to produce a DTM.

The created TIN and the orthophoto related to the small ditch are imported in ArcScene. We planned a symbology with 32 classes from the file property. We used a chromatic scale with light-brown gradation, except for the classes with a lower elevation. For these we used a colour which immediately shows the lower area. We gave transparency to the orthophoto converted in grey scale (so as not to be disturbed by natural colours) and to the TIN, in order to point out the characteristics of the superimposed layer.

Subsequently, to show the slope of the structure faces we used the function slope. This function allows to point out the inclination percentage in the different areas of DTM. With ArcScene we created an image by which it is possible to see the inclination of the shoulder of the small ditch with the chromatic differences. To avoid all images to be coloured again, we prefer to delete the values under a certain percentage (20%) as we do not consider them to be indicative. This visualization is useful to understand the problems given by the photogrammetry in the area of the abutment of the small ditch. The problems are mentioned above, i.e. the stretching of the pixels are located in the areas with a major inclination.

The kiln

After including the control points and the manual and automatic tie points we were able to calculate the aerial triangulation, establishing the mathematic relations between the images which build the block file and the orientation information already included.

Operating the aerial triangulation leads to the creation of a summary containing the principal data on errors (RMSE), the aim of the GCP. The calculated RMSE is equal to 1,2473 unit; the error is acceptable, if we consider the difficulty of catching images through the bar for "aerial photos".

Stereo Analyst, DTM and orthophoto

Once finished the orientation either internal or external, we tested the perfect superimposition of the images belonging to the block file inside the Stereo Analyst. The extremely low error and the optimal photo catching of the block file lead to an excellent superimposition and to an almost perfect stereoscopic vision of the images, except for a small defect of parallax in the direction of the y coordinate. The creation of DTM and of the orthophoto allowed to obtain a tridimensional model of the surface of the kiln and of the stratigraphic units closer to it.

These procedures are useful in the different stages of study and interpretation of the archaeological evidence, after the conclusion of the excavations. They also assume a high documentary value, because the excavation is unrepeatable and unique, but also, at the same time, it is destructive. In this way there is the possibility to have the DTM helping the work of archaeologists in post-excavation stages.

Remote sensing: classification techniques of images and post-classification elaboration

One of the fundamental aims of remote sensing techniques is to produce thematic maps of the tested surface through the images from artificial satellites. In order to create maps quickly, it is necessary to make a ground classification or, as in the case of the kiln[6], a catalogue, according to categories corresponding to a selected standard of research.

There are two methods of classification: supervised and unsupervised. Through a supervised classification the operator can find out the spectral signatures[7] of

[6] In this case, the analysis is done on frames with only 3 bands of visible (RGB). Therefore the processing is simplified if compared to multispectral satellite images.

[7] The signature or spectral response is defined as the "fingerprint" of any object surrounding us. It is a chart that informs us about the amount of energy reflected from a body, according to various wavelengths of the electromagnetic radiation incident.

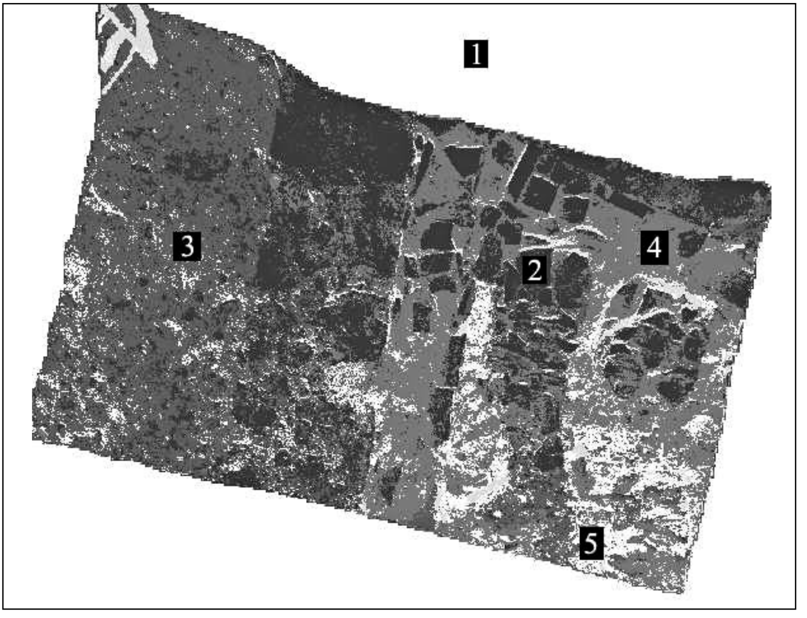

Fig. 4 –

well-known categories[8]. Secondly particular types of algorithms correlate each pixel of the image to any Training Set[9] of reference, matching or similar to our spectral signature.

The second type of classification, i.e. the unsupervised, does not require priority information on the classes that it will create. Such classification analyses on the image pixels are divided in the more common spectral groups present in the data. This process is called clustering. Only subsequently the operator finds out the cluster and attributes each of them to recognizable classes.

Unsupervised classification

The unsupervised classification does not require the use of external directions in order to attribute the pixels to the different classes. This type of classification subdivides the classes on the basis of the numeric information present in the data. This process is called clustering and it is based on the statistic grouping of image pixels through a standard of mutual contiguity so that the groups of pixels (or cluster) result internally united and mutually disjointed. Various algorithms can be employed; however the operator can decide how many groups the algorithm

[8] Define, in this way, Signature Training Set reference.

[9] Areas of example. That is, groups of pixels that can be considered representative of a class.

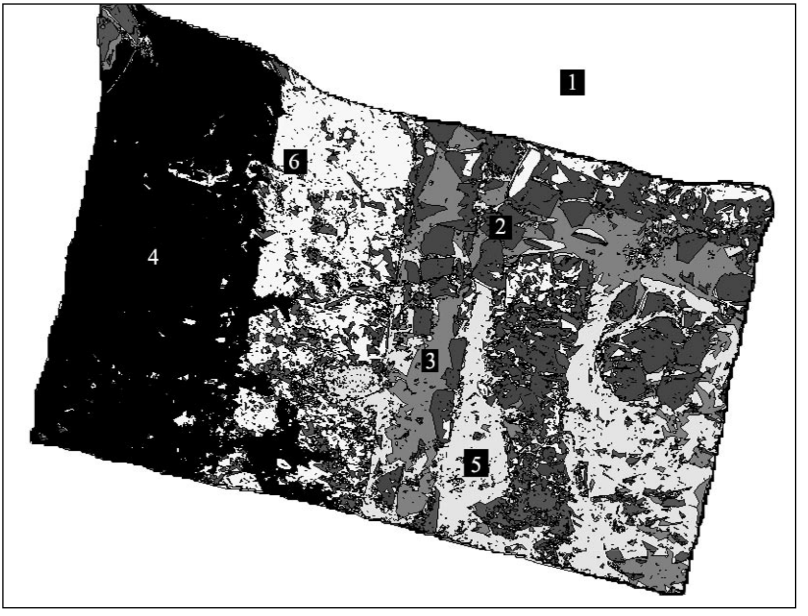

Fig. 5 –

should define. Only after this the operator admits the cluster calculated on the basis of the algorithm to the identified classes.

Isodata is the algorithm of clustering used by software Erdas Imagine. It is a complex heuristic algorithm, based on the principle of assigning each pixel to a cluster with the close centre (minimum spectral distance) and of recalculating the positions of the centers after the elaboration. These are:

– The maximum number of clusters admitted. They point at the greatest number of the classic that can be obtained.
– The threshold of convergence[10]. The threshold value avoids an algorithm to enter a non-ending cycle.
– The maximum number of interactions. It does not allow the algorithm to continue for a long time or to enter a non-ending cycle.

The number of clusters is not defined during the iteration but it can change. For example, when a cluster with a small number of pixels is deleted. The ones very close to each other are united and the ones which are too far from each other are divided. However, at the end of repetitions the number of the classes fixed *a priori* must be restored. The numbers of identified classes for the classification of the

[10] It is the highest percentage of pixels whose assignment to a cluster cannot change from an iteration to another.

kiln are five: 1) Not classified; 2) Tile and bricks; 3) Stratigraphic units 2191; 4) Clay-based ceramics; 4) Embankment.

This subdivision is decided first, on the basis of the knowledge of stratigraphic units tested and represented in the frame[11] (Fig. 4).

Supervised classification

This procedure gives the operator complete control of all the classification process. There are two techniques of parametrical classification:

a) Techniques of parametrical classification. This method is based on a statistical procedure, such as the mean or the matrix of covariance. The algorithms of parametric classification used by the software are the following:

– Minimum Distance: calculates the mean for every band of DN (Digital Number) of pixels belonging to the different signatures. Each pixel will be assigned to the class, the middle point of which is closer (by the Euclidean distance) to the analyzed pixel.

– Mahalanobis Distance: the probability of allotment of one pixel to one class depends not only on the value of its Euclidean distance from the centre of the class but also on the direction.

– Maximum Likelihood: for the classification of each pixel, it will calculate the probability of belonging (i.e. the "similarity") to each defined classes by the signature. Therefore the pixel will be assigned to the class with greater similarity.

b) Techniques of non-parametric classification. A non parametric classifier can use a set of signatures, either parametric or non parametric, and assigns a pixel to each class, by using the rules of geometry.

In order to classify the pixels, it is necessary to use also parametric classification techniques, so that each pixel will be assigned to the class with a higher likelihood[12]. Through this classification method it has been possible to create a reliable group of signatures, useful for a correct classification of the images.

Once located the representative examples of each class, we go on with the digitalizing of polygons on the training sites and to the definition of the spectral signature.

Among the two techniques employed, the parametric method was the better one which classified the image, in particular when using the algorithm of Maximum Likelihood (Fig. 5). For this reason the values of DN have a normal or Gaussian distribution. This means that the frequency of values will be around the mean of each category and go down with increasing distance. This algorithm is the one that has the greatest precision. Unlike the other algorithms, this last created a careful classification, even if not completely exact. Indeed, the so-called "salt and

[11] The orthophoto obtained from photogrammetry is the image used for the implementation of the classifications.

[12] Another possibility is to leave them unclassified.

pepper effect” stays rather high even after carrying out techniques of post-classification elaboration, such as smoothing.

As Fig. 5 shows, the algorithm could perfectly discriminate the 6 classes identified with the polygons in the training set: 1) Not classified; 2) Tile and bricks; 3) Mortar and clay; 4) Stratigraphic unit 2191; 5) Clay-based Ceramics; 6) Travertine blocks.

Post-classification elaborations: raster to vector conversion

The final product of classification is represented by a data raster of thematic type. An attribute, circumscribing its own class of pertinence, is associated to each pixel through its own list of belonging. However, the raw data obtained by the classification often needs a series of improvements to develop the informative context. These procedures, called post-classification elaborations, are the smoothing and the conversion raster to vector.

After the smoothing, we change the original file, in a raster format, into a new file of vector type. This process happens automatically, with the creation of polygons which have pixels of some characteristics. The vector file allows a better visualization of the classified image, and allows an easier and faster editing by the operator.

Through this function it is possible to export a vector editable file (Fig. 5) inside ArcGIS, and once inserted inside the excavation GIS it becomes a functional unit of the same GIS.

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