

# TERRESTRIAL LASER SCANNER DATA PROCESSING

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## ABSTRACT:

The introduction of new terrestrial laser scanner devices in the survey field has increased the possibility of more accurate and complete 3D models of the acquired objects to be obtained. This happens, above all, in the architectural and archaeological survey field in which the shape of an object is usually remarkably complex. Acquisition with laser scanner devices is, in addition, very fast and cheap and the 3D models that are obtained are very useful for users. However, particular attention must be paid during the analysis, the processing and the modelling phases of the laser scanner data.

The acquired data are often characterized by the presence of elevated noise (usually gross errors and outliers) which must be removed with *ad hoc* techniques before starting with the manipulation of the data.

Usually architectural and archaeological objects have a very complex shape and one scan is not enough to obtain the complete description of the object. In these cases, in order to eliminate the shaded areas, two or more scans must be taken from different points of view of the same object. To obtain the final 3D model of the object it is therefore necessary to align and to georefer the single scans using suitable registration techniques.

In addition, when it is necessary to align a large series of scans, the use of triangulation algorithms represents the only way to avoid distortions of the 3D model, in complete analogy with the case of long single strips in photogrammetry.

All these aspects have been considered and a specific software that is able to correctly process terrestrial laser scanner data has been developed by the authors. The paper presents the algorithms and the solutions adopted in order to prepare the laser scanner data to the subsequent work phases.

## 1. LASER SCANNERS

### 1.1 Terrestrial laser scanners

Recently new instruments have been introduced in the field of surveying that are able to acquire portions of land and objects of various shapes and sizes in a quick and cheap way. These instruments, based on laser technology, are commonly known as terrestrial laser scanners.

While laser scanner instruments based on the triangulation principle and high degrees of precision (less than 1 mm) have been widely used since '80s, the TOF (Time Of Flight) instruments have been developed for metric survey applications only in the last 5 years.

These type of laser scanners can be considered as highly automated total stations. They are usually made up of a laser, that has been optimised for high speed surveying, and of a set of mechanisms that allows the laser beam to be directed in space in a range that varies according to the instrument that is being used.

For each acquired points a distance is measured on a known direction: X, Y and Z coordinates of a point can be computed for each recorded distance-direction

Laser scanners allow millions of points to be recorded in a few minutes..

Because of their practicality and versatility, these kinds of instruments are today widely used in the field of architectural, archaeological and environmental surveying.

## 2. THE TREATMENT OF LASER SCANNER DATA

### 2.1 Laser scanner data

As mentioned before terrestrial laser scanners can be considered as highly automatic motorised total stations.

Unlike total stations however, where the operator directly chooses the points to be surveyed, laser scanners randomly acquire a dense set of points. The operator only selects the portion of the object he wishes to acquire and the density of the points he desires in the scan (usually the angular step of the scan in vertical and horizontal planes can be selected by the operator). Once these initial values have been choosen, the acquisition is completely automatic.

The result of the laser survey is a very dense points cloud (also called DDSM – Dense Digital Surface Model). For each point of the model the X, Y, and Z coordinates and the reflectivity value are known.

As this set of points is acquired in a completely arbitrary way, with the exception of the parameters imposed by the operator, it is necessary to manage this data in a critical and reasonable way. Particular attention must be paid to the quality of the original data.

### 2.2 Laser scanner data treatment

The laser scanner data treatment consists of a set of actions that are necessary to obtain the correct digital model of the

object, starting from a set of point clouds. This set of actions can be divided into 2 different stages:

- the pre-treatment (or preliminary treatment) of the laser data;
- the solid modelling of the point cloud.

As “preliminary treatment” we mean all the operations that are directly carried out on the point cloud, such as, for example, the data filtering (noise reduction), the point clouds registration and georeferencing operations. The result of these procedures is a complex “noise free” point cloud (without outliers, gross and systematic errors) and this is the correct starting point for the second stage of the treatment of laser data: the 3D modelling.

The second part of the laser scanner data management, the 3D modelling, is a set of operations that, starting from any point cloud, allows a surface model of the object to be formed.

While there is a huge range of different products on the market to carry out solid modelling, just few software for a correct preliminary treatment of terrestrial laser scanner data can be found.

### 3. THE LSR 2004 SOFTWARE

#### 3.1 The LSR 2004

LSR 2004 (Laser Scanner Registration) is a software package for the preliminary laser scanner data treatment that has been developed by the authors. This software was written completely in Visual Basic 6.0 language and manage also some products directly obtainable from point clouds without any modelling phase.(e.g. Solid Image, Orthophoto and True Orthophoto production).

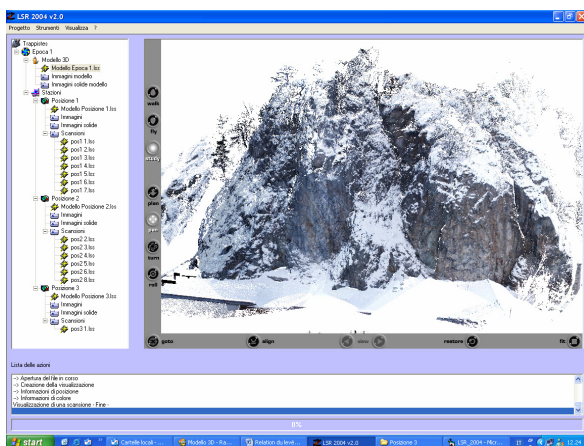


Figure 1. The LSR 2004 software package

LSR 2004 allows:

- point clouds and high resolution digital images to be imported and exported;
- acquired point clouds to be filtered in order to remove outliers and gross errors;
- position of the high reflectivity points (markers) arranged on the acquired object to be determined automatically;
- adjacent scans to be registered and/or georeferenced automatically using reference markers;
- laser triangulation to be carried out in the case of a set of scans;

- digital Images to be calibrated;
- solid Image and its applications (3D colour model and artificial stereoscopic pair) to be created and managed;
- direct measurements to be carried out on the Solid Image.

Some of these procedures are here described.

#### 3.2 Search for the high reflectivity points

Modern laser scanner devices record, for each acquired point, the direction of the laser beam (horizontal and vertical angles are recorded), the measured distance and the reflectivity values (e.g. the energy reflected by the measured point). This set of information make possible to calculate the 3D coordinates of each point using well known geometric equations.

Reflectivity information is still not frequently used in commercial software, but it should not be ignored when dealing with research or specific applications. The reflectivity value is in fact connected to the type of material that makes up the object, an aspect that can be of fundamental importance in the analysis and development of automatic algorithms or in a first classification of the materials.

One of the possibilities offered by knowing this set of information is the opportunity of automatically register (or georefer) two adjacent point clouds. To do this, it is sufficient to arrange some high reflectivity stickers (markers) on the object during the scan.

When the laser beam strikes the markers, the recorded reflectivity value is very high and is usually much higher than the one recorded on natural points (for example, rock, wood etc). If this simple property is used, it is possible to automatically identify the position of the markers inside the 3D model acquired with the laser scanner.

The markers should however be suitably sized and arranged on the object if a correct determination of their position is to be obtained. Their position and size have to be planned considering the laser-object distance, the used angular resolution and the mean inclination of the measuring directions.



Figure 2. The markers

A specific search algorithm has been implemented inside the LSR 2004 software. This algorithm runs in two subsequent steps.

First of all, all the points with a reflectivity value higher than an imposed minimum are identified inside the 3D model. This value can be manually established by the operator or automatically obtained by the computer. In this case, the minimum value imposed for the point search is determined by evaluating the reflectivity histograms of all the 3D model points.

The second step of the proposed algorithm may possible clustering the identified points in order to group all the points that describes the same reflecting marker. In fact a marker positioned on the object can be struck more than once by the laser beam. For this reason it is necessary to group those that refer to the same marker together. The position of each marker is calculated through a weighted mean (in function of

the reflectivity value) of the position of the points belonging to the same set of points.

### 3.3 Data noise reduction

One of the fundamental operations of the terrestrial laser data preliminary treatment is filtering. In fact the data acquired by laser scanner devices always has noises which are smaller than the tolerance of the used instruments.

The noise is due to the divergence of the laser beam which causes an incorrect evaluation of the distance between the object and the origin of the beam. This noise can be easily seen if one tries to create a 3D photographic model of the object (see figure 4).



Figure 4. Projection of the image on an original 3D model (left). Projection of the image on a 3D model depurated of the disturbance (right).

The noisy data do not allow a correct interpretation of the object details. In order to obtain a “noise free” model of the object, it is necessary to use specific algorithms that are able to reduce or eliminate, as much as possible, the acquisition errors that can be found in the point clouds.

The LSR 2004 filtering algorithm was developed by exploiting the following principle in a robust statistical approach. The point cloud is divided into regular meshes according to the horizontal and vertical angular acquisition step. The size of the mesh is chosen directly by the operator and is a function of the acquisition scan step and of the point density one wishes to obtain at the end of the filtering phase (the filtering step should usually be equal to twice the scan step so that there are at least 4 points in each mesh, the minimum possible for a reasonable noise reduction).

Each mesh contains a set of measured points. The median of the distances is estimated and the deviations of the single values are computed from their median.

The distances which have smaller differenced than the laser scanner accuracy are used for the estimation of the real distance using the mean; the other points are rejected (see Figure 3).

This technique also allows the removal of any points which are not on the object of interest (e.g. trees, cars, etc.).

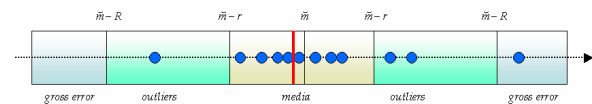


Figure 3. Evaluation of the outliers through the determination of the median value

The proposed procedure was tested by comparing the laser scanner 3D model before and after filtering with a 3D model obtained using classical photogrammetric techniques. The differences of the laser scanner 3D model (before and after filtering) with the photogrammetric model were evaluated.

Figure 5 shows the obtainable results: green, yellow, red and black dots represent respectively the points where the differences between the two compared DEM is less than  $\sigma$ ,  $2\sigma$ ,  $3\sigma$  and  $4\sigma$  ( $\sigma$  is the instrument accuracy). Using the original data coming from the laser scanner instrument the percentage of yellow points is of about a 30% of the total. After the filtering process that percentage rise up to 80% of the total number of acquired points and no red and black points can be found.

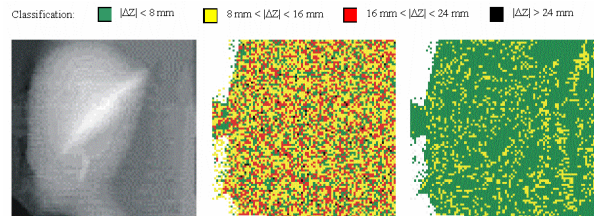


Figure 5. Photogrammetric DEM (left), Laser and photogrammetric DEM difference before filtering (centre), Laser and photogrammetric difference after filtering (right).

The implemented algorithms are also able to remove any scattered points that do not belong to the object (vegetation, cars in movement, people, urban furnishings etc.).

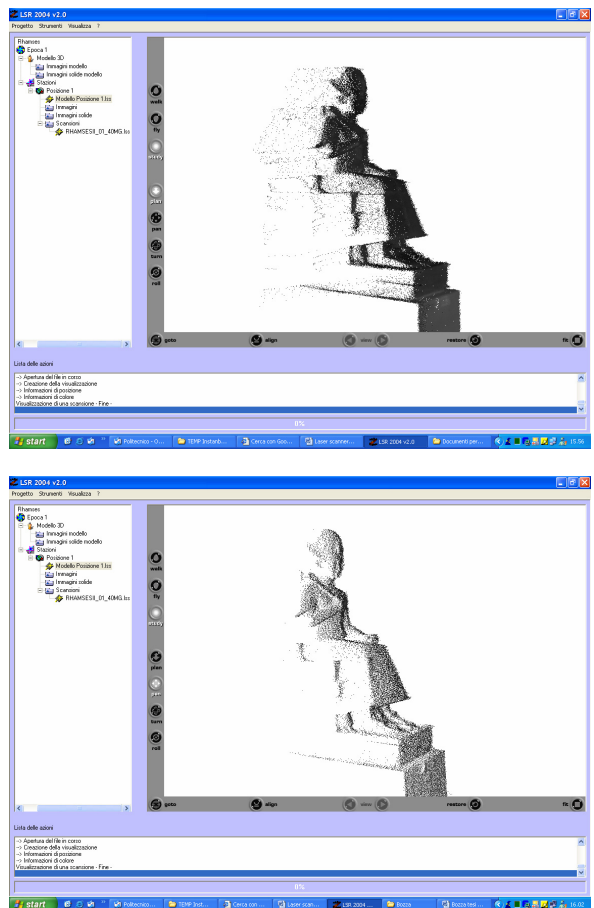


Figure 6. Example of a 3D model before filtering (on the left) and after filtering (on the right).

### 3.4 Point clouds alignment and/or georeferencing

In most cases (when the object has a complex shape) a single scan is not sufficient to record the whole object. In these cases a series of scans must be performed but each scan has

own reference system. The reconstruction of the 3D model of the surveyed object than requires the registration of the scans in a unique (local or general) reference system.

This phase can be performed in an interactive environment through the identification of the homologous points (e.g. corners) inside the overlapping portion of two adjacent scans. Once the points (at least three) are collected, a simple 6 parameter transformation (3 rotations and 3 translations) can be estimated and all the points of a scan can be changed into the coordinate system of a scan that has been assumed as the reference system.

If this simple approach is followed, all the scans that describe an object can be referred to a single coordinate system (e.g. the first scan coordinate system or an external system defined by at least three points).

The collection of tie points and the search of the homologous inside the adjacent scans can be performed automatically using reflecting targets. The reflecting target must be placed on the object in such a way that at least three targets can be found in the overlapping portion of two adjacent scans. The size of the target must be large enough to allow the laser scanner to record it and their displacement has to avoid the alignment of them.

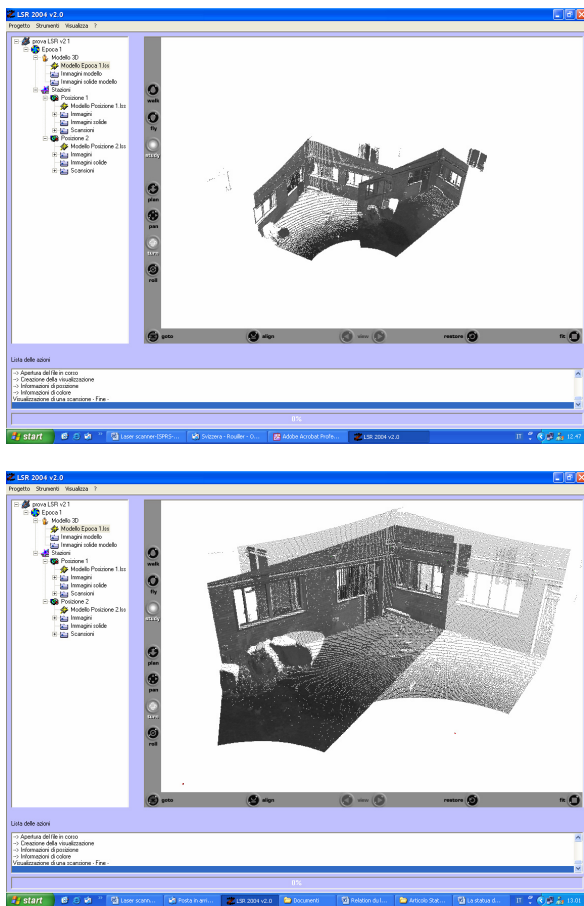


Figure 7. Example of data before alignment (above) and after alignment (below).

The LSR 2004 automatic register unit has been developed using the following criteria.

Let us consider two adjacent overlapping scans. Some reflecting targets (at least three) have been placed in the overlapping portion and recorded by the laser scanner. All these targets can easily be automatically found (see par. 3.2) and their coordinates can be recorded.

The purpose of this procedure is to connect each point of the right scan to the homologous point of the left scan; the reference system of the left scan (for example) is fixed and only the points recorded by the right scan can rotate and translate in space.

In each scan 2 markers that have the same distance in between (only avoiding the instrument tolerance) are chosen. These first 2 markers (in each marker point set) are used to define a spherical coordinate system. Using this reference system the spherical coordinates of the remaining points are then determined. A comparison between these two sets of spherical point coordinates is carried out evaluating the relative geometric distribution. The result of the comparison is a number of connection points that can be found in the two identified sets of markers.

This procedure is iterated for all the others possible 2 points combination. The solution that generates the greatest number of connection points is considered the searched one.

If the number of the identified homologous points is greater than 3 (the minimum conditions for the registration of two models) and if they are not aligned, it is possible to proceed with the registration, otherwise the procedure ask for the operator intervention.

The estimation of the six parameters of a 3D coordinate transformation is performed using the accepted homologous points. All the points of the right scan can then be transferred into the reference system of the left scan using a well known rototranslation model.

At the end of the process, the rototranslation parameters of the point cloud (3 rotations and 3 translations in the space), the identified connection point coordinates, the rototranslated point rejects and the route mean square of the estimation are shown in a specific window in order to give to the user the possibility to test the quality of the automatic procedure.

Using LSR 2004, it is also possible to georefer a 3D model in an external reference system. To do this, the user has just to know the markers coordinates that can be found in a scan, even in an external reference system. The homologous points extraction and the point cloud 3D rototranslation occurs in the same way as described for the alignment of two adjacent scans.

From a practical and economic point of view is interesting to determine the minimum overlap between two adjacent scans.

It is easy to understand that the precision of the registration is directly correlated to the “distance” between the alignment of the tie-points and their true location. As a consequence, the minimum area circumscribing the optimal tie-point location can be interpreted as the minimum required overlap between two adjacent scans.

In order to define the minimum overlapping area between two adjacent scans, some tests have been performed.

We considered in particular couples of adjacent scans with overlaps ranging from 90% to 10%. In each case three tie-points and three check-points (not used for the estimation of the transformation parameters) have been signalled.

Analysing the discrepancies of the check-points it is possible to demonstrate that a minimum of 30% of overlap will assure a final precision comparable to the instrument accuracy.

In this case is not necessary to provide control points and the registration can be performed in the reference system of one of the two involved scans.

The necessity to refer the survey to an external reference system can be performed at the end of the process using the procedure described in par. 3.4.

### 3.5 Laser scanner triangulation

Very large object and/or complex shape of the object require the multiscan registration. If one tries to register all the scans using the above described algorithms at the end of the process unexpected and unacceptable deformation of the final 3D model arises.

Simply connecting 8 scans with a 30% of overlapping on a 40 m length façade the discrepancies tested on a set of check



points are of about 2 m!

The registration of a long chain of scans can be seen as the problem of the photogrammetric triangulation of a single strip. In these cases a series of control points, referred to an external reference system, must be provided.

In order to define the minimum control point needed, some tests have been performed. At least one control point each three adjacent scans must be provided avoiding the alignment of them. Using a minimum overlap of 30% the final precision is compatible with the range accuracy of the used laser scanner.

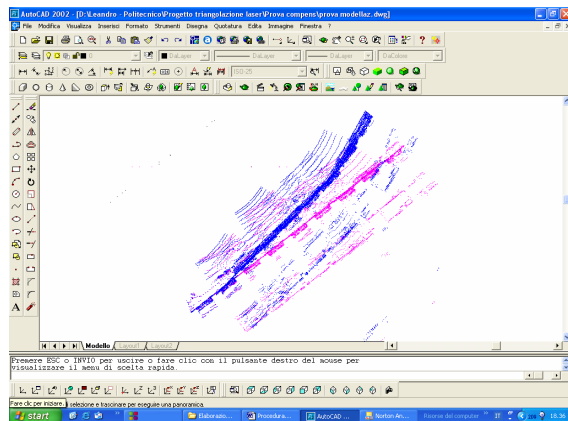


Figure 8. Example of a laser alignment with small overlapping area - before the triangulation process (left) and after a triangulation operation (right).

In order to reach the expecting precision, a rigorous adjustment can be performed. Each scan has been considered as a separate object and tie points and control points have been considered with different weights ( $w = 1$  the tie points and  $w = 2$  the control points).

All the fitting parameters can be calculated and all the points of the scans can be transformed in the external reference system.

The good results can be justified if one consider that in independent model photogrammetric triangulation the adjacent model overlap is of about 10% but the projection centre of the common photo with the usual tie-points on the models give a good configuration of the points to be used for the registration. In the case of the laser scans only tie-points can be used but the minimum overlap of 30% recovers the lack of control information.[Bornaz, 2003].

### 3.6 Management of the digital images and creation of the Solid Image

A digital photo image can be considered, with a good approximation, as a central perspective of the acquired object. If the internal and external orientation parameters of the camera are known, it is possible to establish the direction in the space of each point of the object which is represented by a pixel in the image.

Using a dense digital surface model (DDSM) of the acquired object each pixel (and therefore each direction in the space) can be associated to the distance value between the centre of perspective and the point of the object that is represented by the pixel itself. In this way each pixel can be made to the 3D position of the corresponding point of the object in an appropriate reference system

The integration of the DDSM geometric data with the image radiometric data allows the new concept of the solid image to be obtained [Bornaz, 2003].

Solid images can be used in architectural, archaeological and land surveying applications to determine, in real time, the position of any point in a 3D reference system, using a common PC or to carry out correct three-dimensional measurements (lines, areas, volumes, angles, ...), by just selecting some points on the image.

Oriented images and related DDSM allow one to automatically produce artificial stereoscopic pairs and 3D colour model.

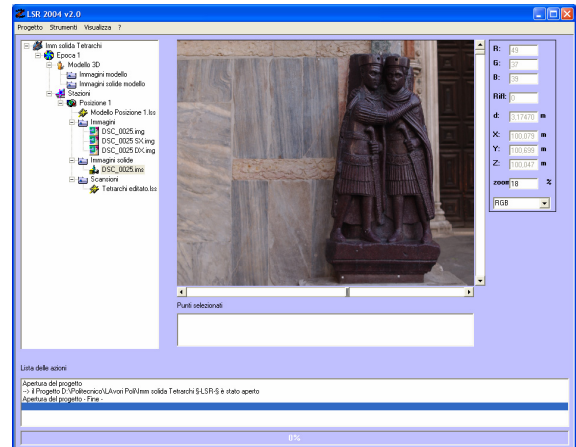


Figure 9. The LSR 2004 software – Solid Image of the Tetrarchi statue in Venice.

Using LSR 2004 software it is possible to import and manage digital images, calculate their calibration and orientation parameters and create the Solid Image and their related products [Bornaz, 2003]

## 4 EXAMPLES OF TERRESTRIAL LASER DATA TREATMENTS

All the described procedure has been performed on different objects acquired with laser scanner devices. Some examples are shown:

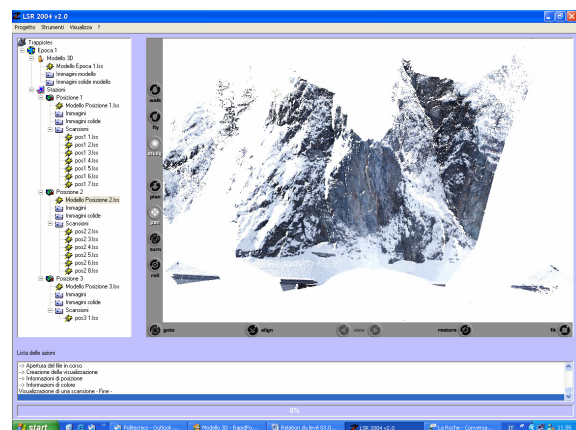


Figure 10. Trappistes (CH) – A rocks slope during pre-treatment phases.

The following figures show the use of the L.S.R. 2004 software during the management of all of the pre-treatment phases.

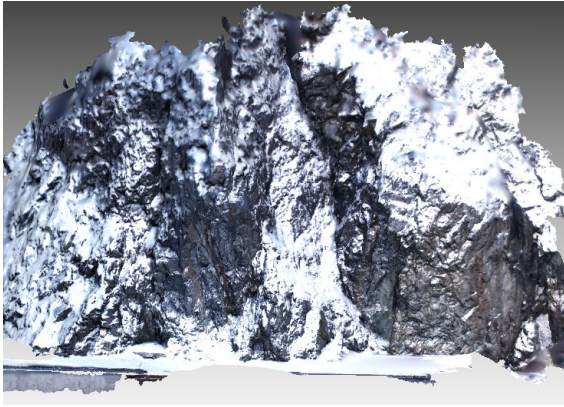


Figure 11. Trappistes (CH) – A rocks slope. Model after the 3D modelling process.

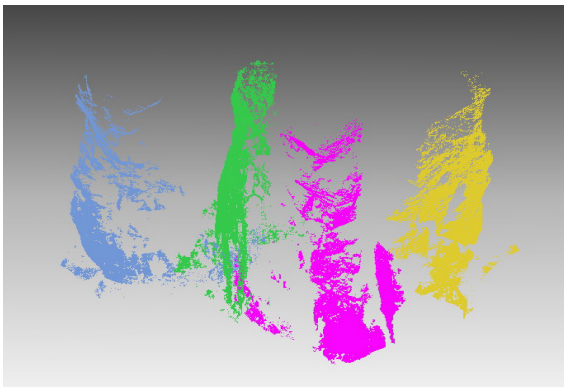


Figure 12. The Saint Jacques tower – Allèves – France – Model before the alignment process.

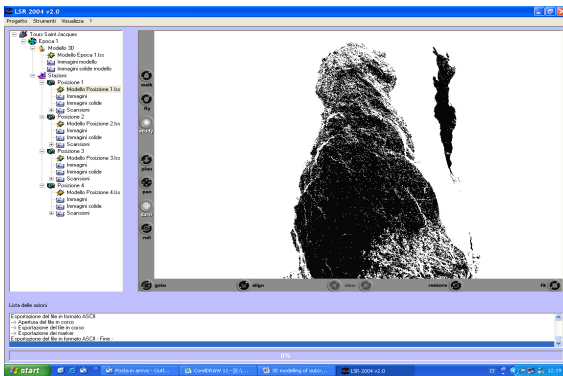


Figure 13. The Saint Jacques tower – Allèves – France – Model during the alignment process performed with LSR 2004.

## 5. CONCLUSIONS

The use of terrestrial laser scanners for the survey of architectural and natural objects is the most promising techniques in order to achieve quick and complete 3D information.

The data coming from the laser scanner instruments can not be used without a correct approach.

The algorithms developed by L.S.R. 2004 software offer the possibility of carrying out all the needed procedures offering

to the user the possibility to test the quality of the acquired data..

L.S.R. 2004 is a completely automatic software package that only requires the operator interaction for some procedures in order to allow the maximum flexibility of the work..

The use of targeted points is the most affordable way to perform the registration of multiple scans.

L.S.R. 2004 software also offers the possibility of creating and managing the Solid Image, a new research product that opens the way to a series of new challenges in the architectural, archaeological and natural objects survey.

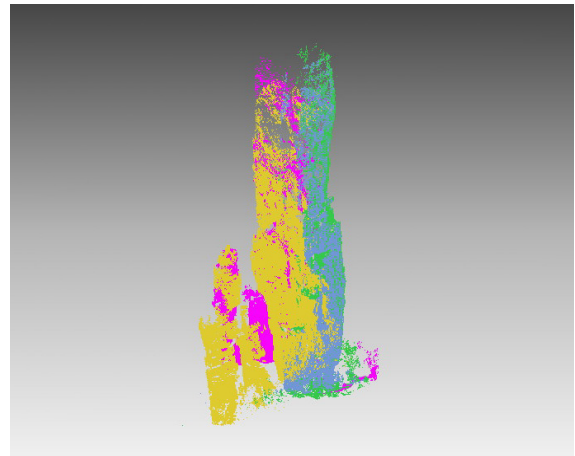


Figure 14. The Saint Jacques tower – Allèves – France – Model after the alignment process.

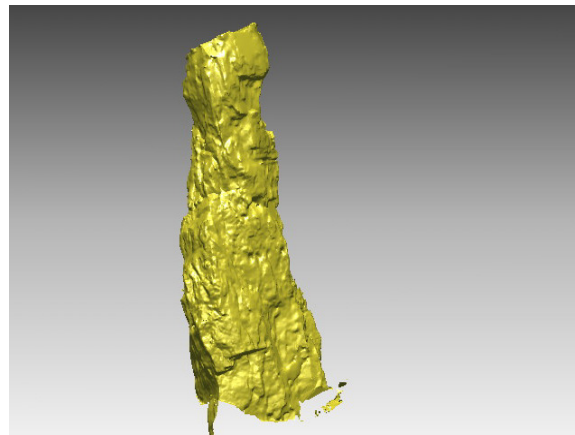


Figure 15. The Saint Jacques tower – Allèves – France – Model after the 3D modelling process.

The data coming out from the L.S.R. 2004 software can be used for a correct 3D modelling using one of the well known commercial softwares.

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