

THE THREE DIMENSIONAL LASER SCANNER SYSTEM: THE NEW FRONTIER FOR SURVEYING. CASE HISTORY: THE LEANING TOWER OF PISA (ITALY), THE ANCIENT THEATRE OF TAORMINA (ITALY), THE PREHISTORIC SITE OF NOLA (NAPLES-ITALY).

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ABSTRACT:

Some of the results of surveys carried out at the Leaning Tower of Pisa (Italy), the ancient theatre of Taormina (Italy), the prehistoric site of Nola (Naples-Italy) are detailed in this work.

The aim of the survey of the Leaning Tower of Pisa was in particular to evaluate the extent of the lean and it is the understanding of which that is essential for any consolidation work.

The main goal about the survey of the theatre of Taormina has been the masonry analysis performed in few days.

At the end, the survey of the prehistoric site of Nola has given a “digital preservation” of a 3.700 b.y. ancient village destroyed by Vesuvius volcanic eruption.

The survey was carried out using a portable 3D laser scanning system “CyraX 2500” which captures, visualizes and models structures with an unprecedented combination of completeness, speed and accuracy.

In this survey the complete surface geometry of the exposed surfaces was remotely captured in a form of dense, accurate “3D point clouds”, ready for immediate use. The next step was to draw the horizontal and vertical sections, making use of the large measurement data base that had been compiled on site. This was done utilizing dedicated modelling software.

1. MANUSCRIPT

1.1 Introduction.

It is recognised that to conduct any kind of planning and subsequent restoration or consolidation work on a historical building it is essential to acquire and evaluate in advance all the necessary data of a technical, architectural and geomorphological nature. A comprehensive and objective survey demonstrates all the geometric characteristics, textural elements and structural defiance of the building. This is the fundamental starting point from which to proceed with both further studies and the project itself.

Following on from this, it is easy to deduce the importance of a survey carried out as objectively as possible, above all considering the number and the variability of the situation and the difficulty of interpreting the collected data.

All this justifies the importance of using advanced surveying techniques such as a 3D laser scanner in order to reduce to a minimum the mistakes made due to the interpretation of data. Furthermore, such a technique allows you to obtain a large and rich data base, which demonstrates the state of a building at a specified moment of its history and is consultable whenever necessary.

The following cases represent examples of the application of this new 3D laser technology and demonstrate the favourable results possible using this method, both to compile the data base in the field and to elaborate the data once back in the studio.

1.2 A description of 3D laser scanner methodology.

Laser scanner technology was introduced in the 1990s when in 1995 *Cyra* produced its first laser scanner.

A laser scanner uses a pulsed laser, that produces up to 1,000 distinct, individual dots (or surface geometry measurements) in each columnar sweep and then measures the time-of-flight for each point. To do so with millimetre accuracy, the scanner is equipped with a timing device that measures picoseconds. *CyraX* can also focus a narrow beam and maintain a small dot size over long distances.

The scanner captures four pieces of information for each individual dot (surface geometry measurement): the x, y, z coordinates and a return intensity, this information is then used to map a colour or grayscale over the cloud.

The image that appears on the computer screen is a 3D cloud, which, depending on the scan density and technologies used, can capture minute details.

The 3D laser scans and the point-cloud processing software applies colours to a point cloud and creates an instant 3D shrink-wrap computer image. This image looks like a 3D photograph - the 3D image can be reviewed from any perspective. Visualisation via the shrink-wraps, while very useful, is only one of the capabilities offered by *Cyclone*. As soon as scanning is finished, a user can click on any two points within the point cloud and obtain immediate distance measurement between the two selected points.

Once the point clouds are registered together, designers use softwares to process the data into CAD models of the existing structures.

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CAD modelling of existing structures in 3D is a very involved and time-consuming activity. The results are only as good as the input measurements. Potentially erroneous assumptions are built into both the measurements and the reconstruction, such as walls being flat and perpendicular to the floor and ceiling.

Creating a 3D point cloud of even a large and complex monument, using Cyra technology, takes few hours rather than the weeks required by traditional geometry capture methods and CAD.

2. CASE HISTORY: THE LEANING TOWER OF PISA (ITALY), THE ANCIENT THEATRE OF TAORMINA (ITALY), THE PREHISTORIC SITE OF NOLA (NAPLES-ITALY).

2.1 The Leaning Tower of Pisa (Italy).

In May 2001 when the safeguard and conservation work had been completed, a 3D scanner survey was carried out. The survey which took only three days was done in order to compile a data base of the monument and to measure some important parameters such as the extent of the lean and the deformation suffered by the structure.

Four shooting positions were necessary to compile the data relative to the whole volume of the monument. Twenty-six spheres made in polystyrene were positioned on the tower at different levels and on the ground surrounding the monument. This was to allow the connection of the four point clouds obtained from the four shoots and to create the complete 3D image of the tower. The image can be viewed from any perspective. The scanner survey was also referenced by a topographical survey.

2.2 Brief history of the leaning Tower of Pisa

The Leaning Tower of Pisa is the bell tower of the Cathedral. It became renowned the world over for its peculiar inclination, but even without its famous fault the Leaning Tower would have still become one of Europe's most remarkable architectural structures.

Its construction began in the 1173, but took almost two hundred years to complete.

By 1178 the third story was complete. It was observed at this stage that the tower was leaning to the north. Construction was put on hold until 1275 due to wars with neighbouring provinces.



Figure 1. The Leaning Tower of Pisa – Italy. A rendering of the monument

By this time the tower had shifted of its own accord and was now leaning to the south. A further three floors were added but rather than following the original tilt of the lower levels they were built perpendicular to the ground

The analysis carried out 30 years ago of the leaning angle of brick layers pointed out that the axis of the tower is bent. In fact, at about one quarter of the way up on the fourth story a variation of the axis angle is evident. This variation was made while the tower was being built to attempt to correct the lean that the tower had already suffered during the construction process thus far.

Construction stopped again until 1319, when the last two stories were built. The bell was finally placed at the top of the tower in 1350.

Many attempts to correct the Tower's curious lean have been made over the centuries, but some have actually aggravated the situation.

On Saturday, 15 December 2001, after two years of further conservation and stabilization work it was finally possible for the public to go up the tower again.

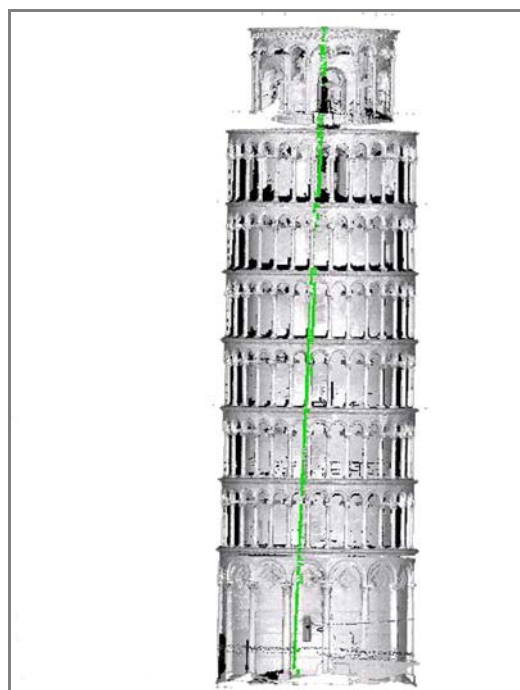


Figure 2. The Leaning Tower of Pisa – Italy. A rendering of the whole monument showing a cross section where the lean is at its greatest.

2.3 A practical application of 3D laser scanner technology: the survey of the Leaning Tower of Pisa.

One of the advantages of using the 3D laser scanner technology is that, as a result of the scanning, it is possible to create a 3D georeferenced point cloud. Each point has known coordinates X, Y and Z which are directly measurable on the screen. By utilizing the modelling software it is also possible to draw both horizontal and vertical sections.

The survey was conducted placing 26 polystyrene spheres in various positions both on the tower and on the ground surrounding it. In particular four spheres were positioned on the fourth floor and four on the seventh floor at 90 degree angles to

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each other. On the ground three of the spheres positioned were done so to form an unequivocally determined horizontal plan. For every scan a surveillance grid of 3 x 3 cm was used and this allowed very detailed data to be collected, as you will see from the images in this document.

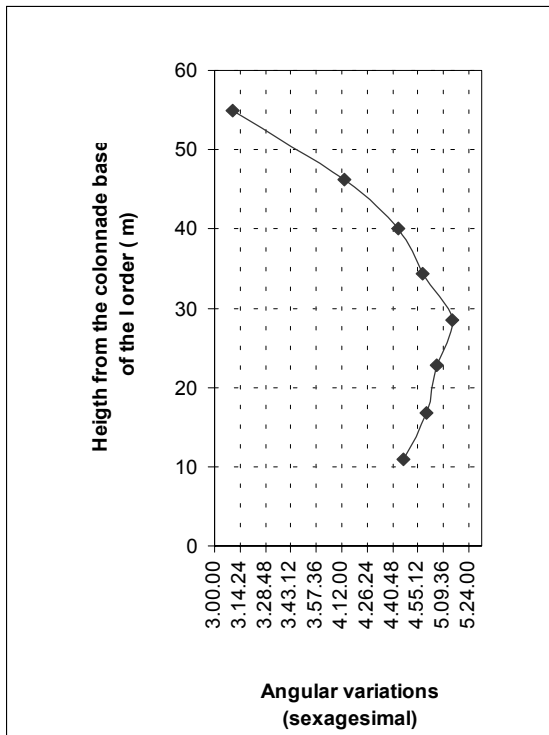


Figure.3 Tower's axis shape along the maximum inclination (2001)

As has already been indicated, using a dedicated graphic modelling programme it has been possible to obtain vertical sections and to measure the lean and the form of the inclination. Figure 4 illustrates how the greatest angular variation exists from the fourth floor upwards.

The feature of the method has allowed of making many sections of the tower. So we've calculated for three different altitude (26, 40 and 47 m) the distance of the centre from the axis of maximum lean (see figure 3 – 4).

Such variations rapidly diminish from the sixth floor where the angular variation is equal to 3°10'00" sexagesimal degrees.

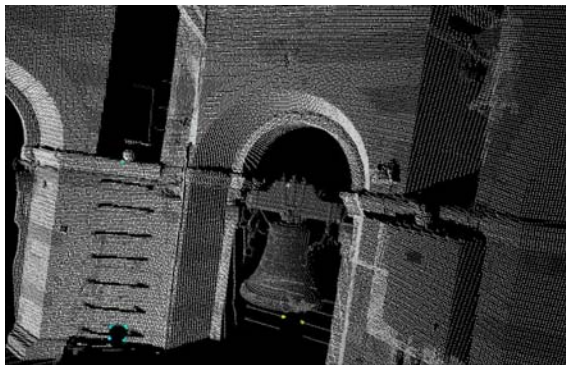


Figure 4. The Leaning Tower of Pisa – Italy. A rendering of the monument

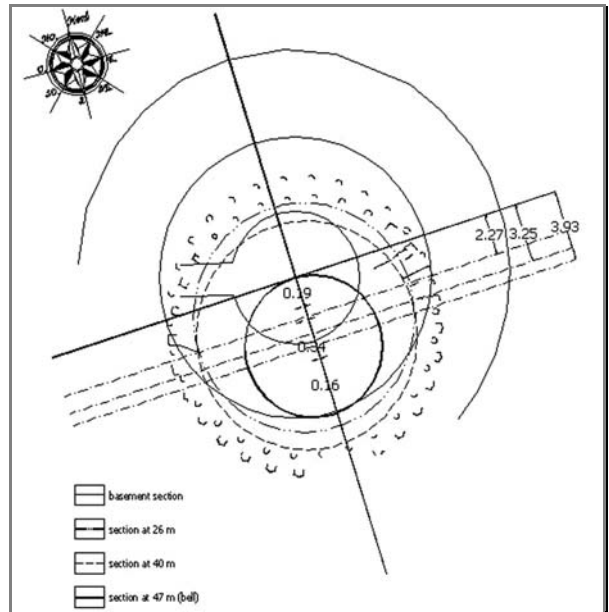


Figure 5. The Leaning Tower of Pisa – Italy. The analysis of the eccentricity.

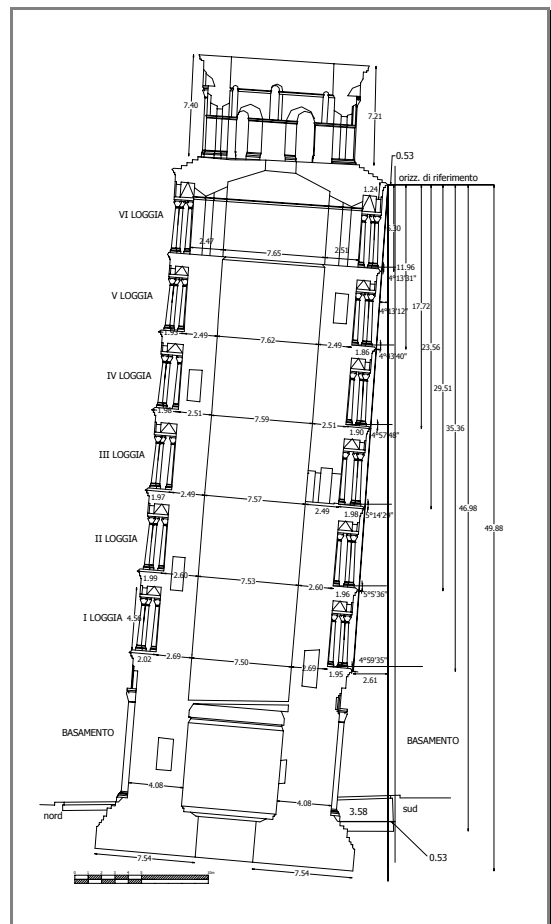


Figure 6. The Leaning Tower of Pisa – Italy. Section axecuted along the plane of greatest inclination.

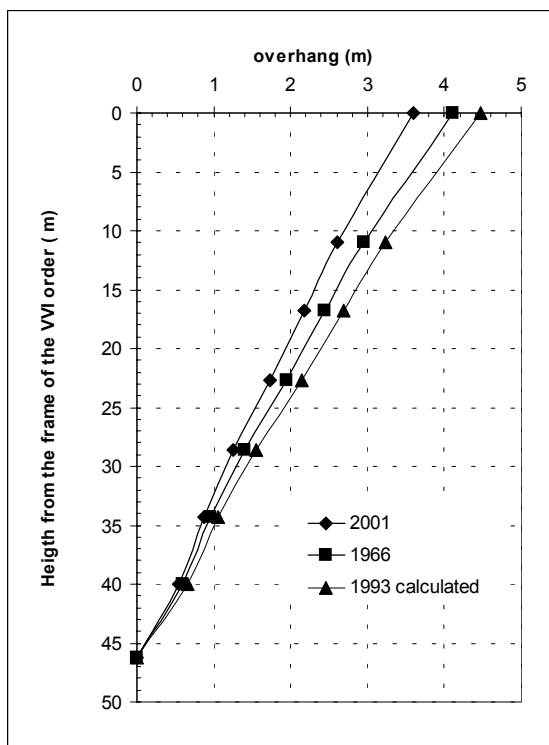


Figure.7 Overhang variations 1966-1993-2001

3. THE ANCIENT THEATRE OF TAORMINA (ITALY)

3.1 Short historical accounts:

Located in the internal portion of the calcareous promontory that stretches toward Taormina Cape, the Greek theatre is outside the urbanised tissue of the town.

Some epigraphic references allow to date this construction in the Hellenistic period, at the time of the tyrant Gerone (II century B. C.). For its dimensions (diameter of the cavea 109 m; section of the orchestra 35 m) and for its majestic and imposing monumentality, the theatre of Taormina in Sicily is second only to the Syracuse one and it constitutes one of the most authoritative testimony of theatrical buildings in Hellenistic and Roman antiquity.

As from the II century Romans acted a radical transformation and reorganization of the installation: in short, they wanted to adapt this grandiose public work to their vision of the amphitheatre and to their taste as regards to performances. The theatre, conceived as a dramatic or musical representation place, gave space to gladiatorial games (*gladiatores*), to naval battles (*naumachiae*) and to hunt spectacles (*venationes*).

All this involved two significant transformations of the original structure of the theatre: the amplification of the orchestra (to adapt it to its new arena function), and the construction of a high podium (to protect the audience from the risks of certain kinds of performances).

The capacious *cavea*, entirely dug-out in the calcareous rock, could receive up to 5.400 spectators. Until today it is divided into nine cuneiform sections, with eight little staircases; in the central sections some ancient blocks have been replaced reconstructing, in this way, the original flight of steps. During the Roman period, two porticoes partly rose completing the

cavea: the superior one was supported by columns; while in the intercolumniations of the lower one there were some niches containing statues.



Figure 8. Rendering of the theatre of Taormina; view of the Scene from the cavea.

3.2 A practical application of 3D laser scanner technology: the survey of the ancient theatre of Taormina (Italy)

The diffusion of laser scanning technique is recent and certainly it will find an increasing expansion in the near future.

Survey is now considered as an analytical and cognitive instrument of fundamental importance; the present technology of the *geomatica* offers, in fact, great opportunities both for the good time of the relief and for the representation and the coding of the metrical data picked up with digital instrumentation.

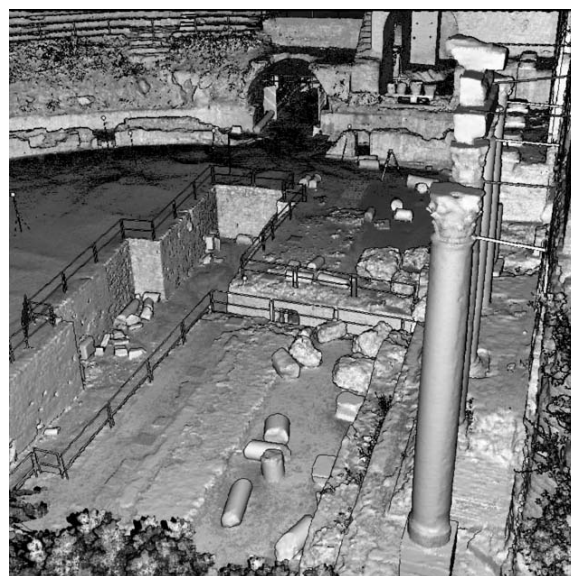


Figure 9. Rendering of the theatre of Taormina; view of the Scene.

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The Tridimensional Survey of the Theatre of Taormina has had the aim of reconstructing the complex geometry of the ancient monument in a detailed and accurate way, making global reconstructions of the monumental building and using a precise range of 2 millimetres, on a grid of 1 square centimetre.

The accuracy of the intervention (next to the millimetre) has allowed to investigate deeply the form of the architectural hand-made article in question and to exceed the purely geometrical information, that were integrated with relevant chromatic and materialistic data.

The software system provides an exact representation of the datum; the final model can be given in a *photorealistic* way, or through the projection on the object of the original texture surveyed by digital photographs or using a



Figura 10 . Rendering of the theatre of Taormina; view of the Scene.

visualization that classifies the points according to the distance from the observer (*intensity map*).

4. THE PREHISTORIC SITE OF NOLA (NAPLES-ITALY).

4.1 Short historical accounts.

During an examination of the territory of Nola (important centre located at a distance of about 25 km from Naples), rich in archaeological monuments, which go from the prehistoric times until the classical ages, it has been discovered a village dated back to the Ancient Bronze buried by the eruption of Avellino, occurred between the XIX and XVII century B.C. The tragical event was called: "Pomici di Avellino" because, during the eruption, the ashes and the pumice-stones fell principally towards North-East, in direction of the above-mentioned town.

In a wide excavation of about 1000 square-metres, deep six metres, three big huts, of great archaeological interest, have been brought to light; these constructions surely were part of a larger agglomerate and were all orientated toward North-West or South-East.

The particular moisture of the soil has kept footsteps of wooden-shoes, oak leaves, some mushrooms and the remains of a lizard. The condition of the houses was exceptional, they had the form of a horse-shoe with an opening on the straight side.

On the entrance of the house there was a sort of penthouse and on the left wall a door opening towards the interior of the house.

In the huts had been found more than 200 vessels, in good conditions, containing: almonds, flour and ears of wheat. The position of some objects showed that the eruption had caught the inhabitants unaware, during their daily activities, in fact around the oven was set out: plates, cups, supports on high foot, while a jug was still in the oven.

After the eruption the village, completely covered by hardened ashes, was struck by a terrible cinereous flood which penetrated in the huts and strenghtened their structures.

This flow, composed of cinereous material and water, created casts of the huts and filled all the objects in them.

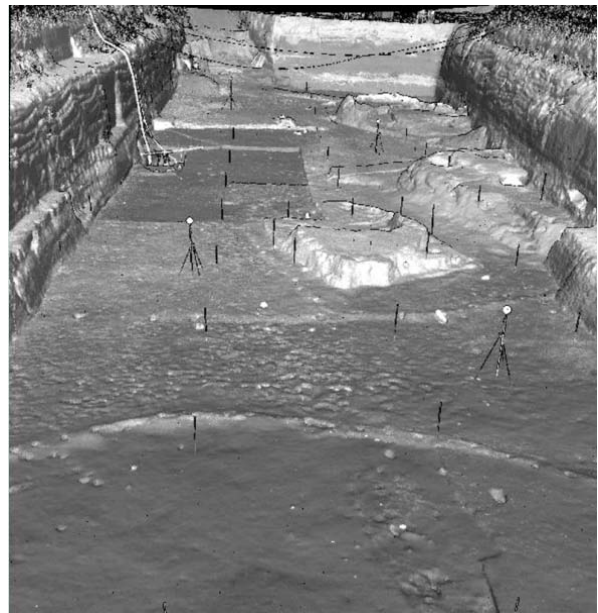


Figura 11 . Rendering of the archaeological site of Nola; overall view.

4.2 A practical application of 3D laser scanner technology: the survey of the prehistoric site of Nola (Naples-Italy).

The application of laser scanner system in archaeological field is very advantageous, in fact it allows to safeguard and survey the artistic patrimony existent in our country.

The precise survey of complex archaeological contexts gives the possibility to create a multimedial database, which can be examined in different historical moments and at different levels, surveying, in this way, the single steps of the excavation.

In the specific case of the site of Nola, the intervention has been characterized by two phases of the excavation: the first one in which the laser scanner has recorded the most superficial discoveries (the pen with kids and the superior parts of the huts), and the second one which has brought to light the complete structures of the huts.

Thanks to the utilization of the tridimensional laser scanner, has been possible to reconstruct the real numerical model of the site

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Figure 12. Rendering of the archaeological site of Nola; overall view.

considered and to record 15 constituent scans which form, in the complex, a cloud of about 5 million georeferenced measure points above sea level and across an high precision topographical survey.

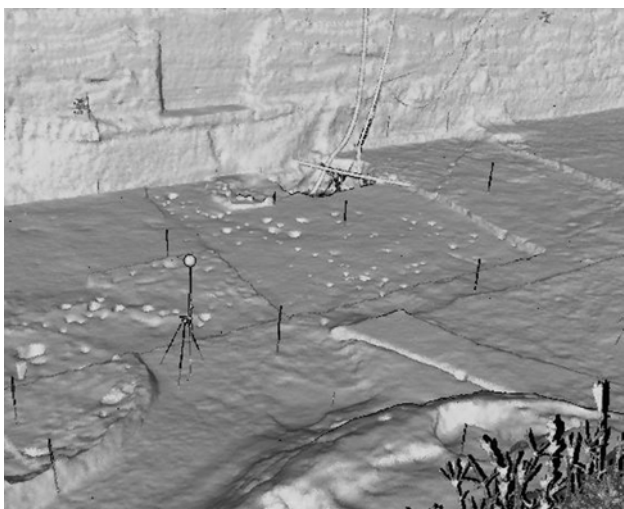


Figure 13. Rendering of the archaeological site of Nola; detailed view.

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4.3 Acknowledgements

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