# Laser scanner technology for complex surveying structures

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*Abstract:* - Generally, when someone refers to architectural property he inclines to consider only that part of architecture and monuments belonging at remote epochs far since our days. However authors' opinion is that the diffusion and the spreading of the culture cannot leave out from the analysis, the study and the conservation also of architecture and all things realized in more recent times. However, the characteristics of the modern and contemporary architecture with respect to those precedents lead to the development of a definition for new approaches and adequate representation forms because of the presence both of materials and innovative technologies like the tubular or trellis structures, that show then different difficulty in the interpretation and definition of the acquired data. In such direction, the new digital technologies allow, from a part, a rationalization and rapidity of the relief operations, from the other they allow to create some new representations which can easily fit to the scholars and operators (architects, engineers, restorers, historians, etc) demands, or to be used to produce faithful copies through quick prototype techniques, but also, more simply, to give back enjoyable such information easily by town councils or web users. The developed and described, in this article, experiences have the aim of verify the potentialities of laser scanner in surveying of structures, for whom traditional techniques of relief could result disadvantageous in terms of realization's times, costs and precision. A particular attention has addressed to elaboration phase, data filtering and 3D modeling through the use of specific and opportune algorithms of best-fitting, useful for individualization and extraction of forms.

*Key-Words:* - TLS, contemporary architecture, 3D modelization, laser scan, radiometric data, survey.

## 1 Introduction

In current paper, the developed and described experiment has the aim to show as laser scanner's technology could be considered a valid option about surveying of structures for whom the traditional survey's techniques could be result disadvantage regarding realization's times and costs. At this purpose, it has found to characterize an architectural object that shows, in addition to an historical, social-cultural and technical value, also a certain complexity of evidence which justify the preference about this new technology in comparison with traditional instruments. The architectural handmade, object of the paper, is a covering (Figs. 1, 2, 3), to protection of the access steps at the submitting railway Reggio Calabria station (ITALY).

It is a recent building going back at the 1990s and the reason of the choice has been determined by the particularity and the complexity of the structure, characterized by the presence of spatial reticular beams to triangular (variable) section, realized with tubular profiles.

Fig.1: View of the covering

Fig.2: Another view of the covering

Fig.3: Detail of the cover

## 2 Survey with Laser Scanner

Laser's survey has been developed, using laser scanner Cirax HDS 3000 (Fig.4) distributed from Leica Geosystems, whose functional characteristics are shown in Table 1.

Fig.4: Laser scanner Leica HDS 3000

| Leica HDS 3000 | |
|---|---|
| Technology | Time Of Flight |
| Max Range | 300 m at 90%; |
| | 134 m at 18% albedo |
| Max Field of View | 360° horizontal |
| | 270° vertical |
| Scan rate | > 4.000 points/sec |
| Window of scan | Double |
| Positiong's precision at 50 m | 6 mm |
| Distance's precision at 50 m | 4 mm |
| Scanning's step | Independents horizontal and vertical |

Table 1: Functional characteristics

The tool is, moreover, equipped with an internal room to CCD with which it acquires the images of the noticed portion, and it's, therefore, able to associate every laser point with a colour's information obtained by the projection of the image over laser data.

Geometry, the number of the holds and the scanning's resolution are strictly connected to the characteristics of the investigated spaces and, at the detail's level, what it wants to obtain. In this case, the structure offered big position's freedom, therefore, the number and the positions of the scanning have been, essentially, dictated by the complexity of the structure (because of the presence of tubular reticular elements), from the possible shade's zones produced by the bodies interposed between the scanner and the object, and from the use of the least necessary targets' number.

They have been realized five instrumental positions, in Fig.5 (obtaining, therefore, others clouds of points), using 12 targets disposed in some positions that, at the purposes of following phase of registration, the various (couples) scanning could have in common at least 4 targets.

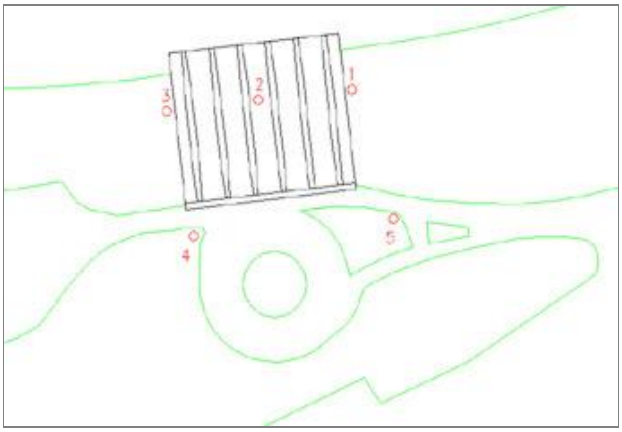

Fig.5 - Area of the relief and recovery project.

The acquisition's phase has been led, using the dedicated software Cyclone™, which allows, once identified the scanning field and fixed the step, to show in real time the noticed clouds of points and to recognize, in automatic way, the centre of the used and fundamental targets (paper and reflectors), Figs. 6, 7, 8 to the next "seam" operation.

Fig.6: Targets used.

Fig.7: Detail of targets black&white

Fig.8 - Detail of targets reflectors

Fig.9: A view during the scan.

Fig.10: Another view during the scan

Fig.11: Another view during the scan

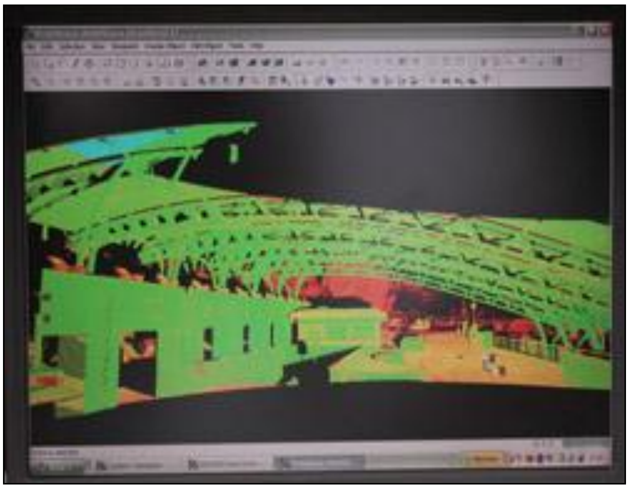

Fig.12: Screen notebook during the scan

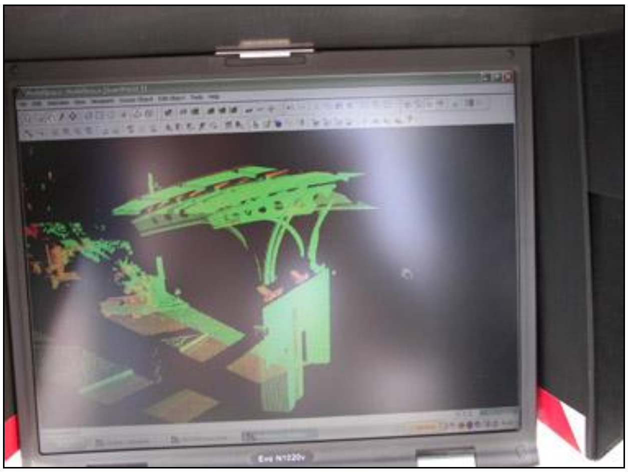

Fig.13: Another view: Screen notebook during the scan

The software, set the field of scanning, also allows to set up scanning (in this case fixed at 1.5 cm) in order to manage the compromise speed/precision obtained, favoring the level of detail and the resulting precision in steps of crawling low, or moderate the time of acquisition with further scanning steps.

| Scan | Step / reference distance | N° target acquired | N° Points acquired |
|---|---|---|---|
| 1 (ext) | 1,5cm / 9mt | 10 | 1170018 |
| 2 (int) | 1,5cm / 5mt | 8 | 1256742 |
| 3 (ext) | 1,5cm / 9mt | 5 | 962996 |
| 4 (ext) | 1,5cm / 5mt | 5 | 570887 |
| 5 (ext) | 1,5cm / 9mt | 4 | 368340 |

Table 2: Scan Features

The necessary time, for all survey's operations (5 scannings), included position's time of instrument and arrangement of targets, has been about 7 hours and it has allowed to acquire quickly a great amount of data (about 4,5 millions of points).

## 3 Elaboration and Restitution of Acquired Data

The treatment of the acquired data has been realized, prevalently, using the proprietary software Cyclone™, supported by opportune algorithms opportunely implemented by authors. Made so the recording of the 5 clouds (Figs. 14, 15) of points produced by the scanning (associating homologous targets), and removing the superfluous points not belonging to the structure, it has obtained one cloud of points, representative of the investigated object.

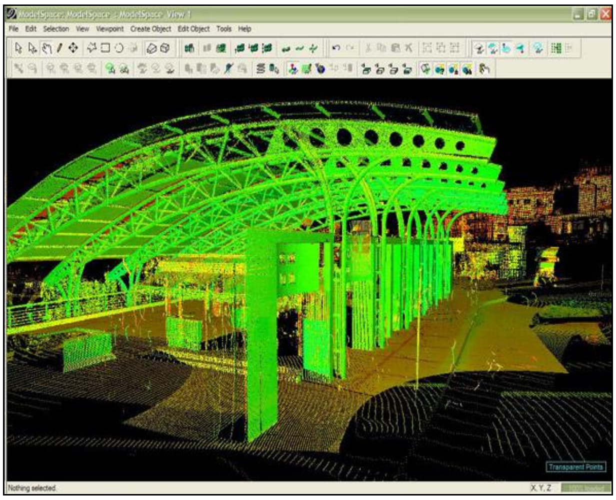

Fig.14: Cloud of points produced from scanning

The three-dimensional model [12] of the object of the survey so obtained, besides the possibility of exploring the structure in its spatiality, constitutes the base from which obtain vector representations.
It also contains all that useful metrical information to make further analyses and investigations. We used, therefore, an algorithm of Texture Mapping (which has provided, moreover, some results comparable with the one inner of the data treatment software) which it has allowed "to spread" (it also dictates mapping's operation), on the cloud of points, the photographic Rgb image acquired by the internal room to the tool, producing such a model 3d (Figs. 17, 18, 19, 20) having a strong realistic impact.

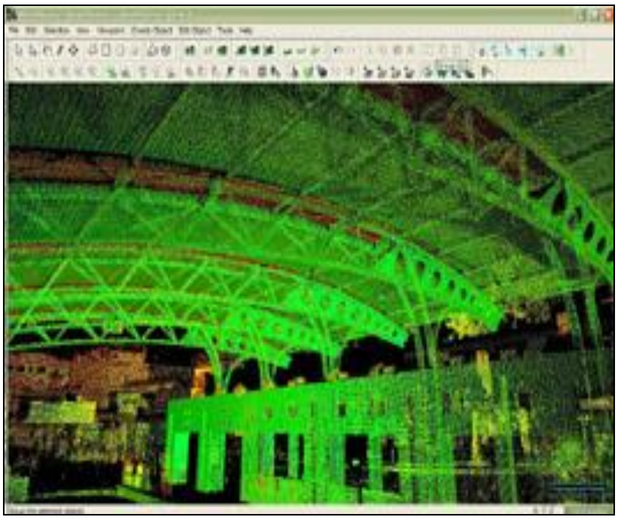

Fig.15: Cloud of points produced from scanning

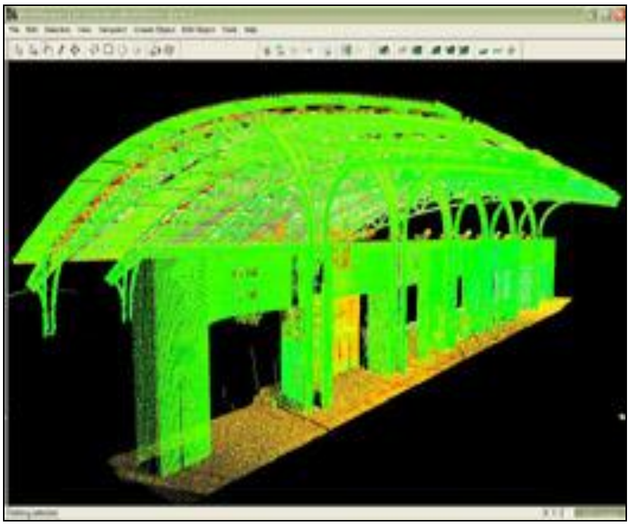

Fig.17: 3D Model

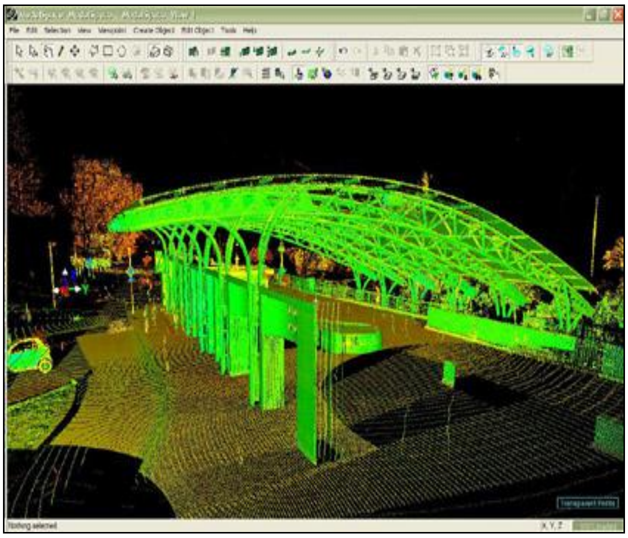

Fig.16: Cloud of points produced from scanning

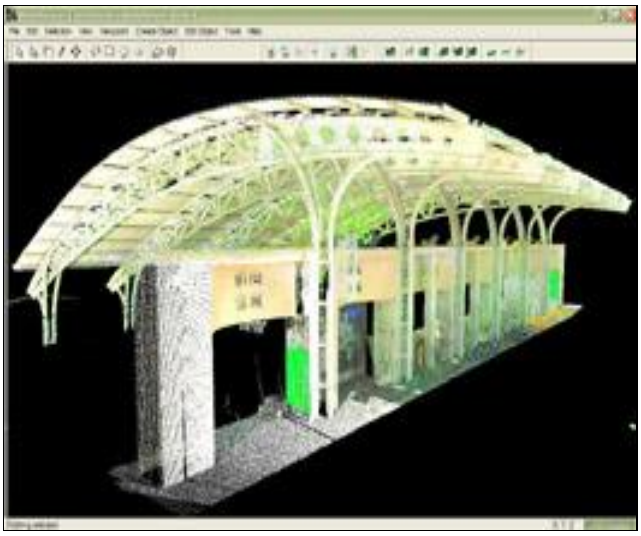

Fig.18: Digital image spread on the cloud of points

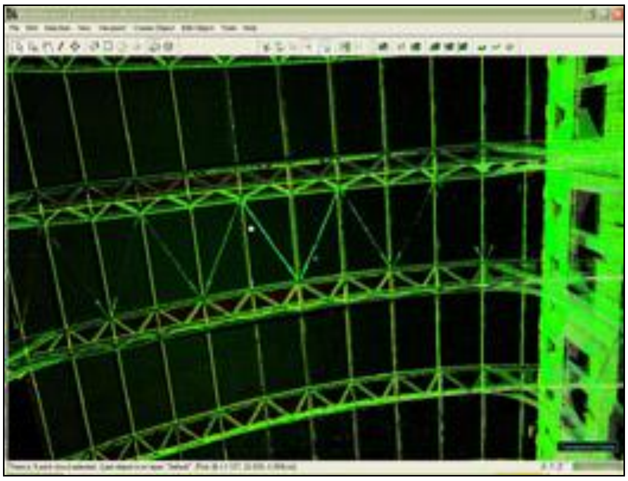

Fig.19: 3D Model of the cover

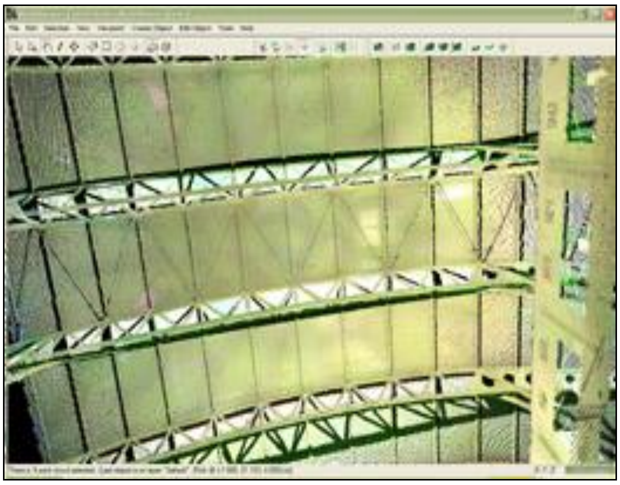

Fig.20: Digital image spread on the cloud of points of the cover

Some particular best-fitting algorithms have been applied, implemented and tested on portions of the structure (Figs. 22, 27) and, in particular, a stroke of the spatial reticular girder and on a pillar, for the semiautomatic recognition of particular forms (plans, spheres, cylinders, etc).

These algorithms, in a first phase, develop an operation of triangulation of points' clouds (Figs. 23, 28), changing points, acquired by scanner, into a superficial representation; after they search the function $Z = f(x,y)$, which it describes, about measurement's wrongs and for a fixed range of wrong's greatness, an opportune mathematic relation which, basing on adaptation and closeness's information, describes and approximates better surface's curvature.

In a specific way, the used local interpolation's function has been the square relation $z = ax^2 + bxy + cy^2 + dx + ey$ with 5 coefficients, calculated solving, with Ordinary Least Squares, the following redundant system of equations:

$$\begin{bmatrix} x_{1,1}^2 & x_{1,1}x_{1,1} & y_{1,1}^2 & x_{1,1} & y_{1,1} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ x_{1,n}^2 & x_{1,n}x_{1,n} & y_{1,n}^2 & x_{1,n} & y_{1,n} \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \\ d \\ e \end{bmatrix} = \begin{bmatrix} z_{1,1} \\ \dots \\ \dots \\ \dots \\ z_{1,n} \end{bmatrix} \quad (1)$$

In order to solve this system, it's necessary to have at least five points (because coefficients are 5). When coefficients are calculated, it's possible to obtain principal curvatures $K_1$ and $K_2$, Gaussian curvature $K$ and mean curvature $H$.

$$K_1 = H + \sqrt{H^2 - K} \quad (2)$$

$$K_2 = H - \sqrt{H^2 - K} \quad (3)$$

$$K = \frac{4ac - b^2}{\left(1 + d^2 + e^2\right)^2} \quad (4)$$

$$H = \frac{a + c + ae^2 - b^2 + cd^2 - bde}{\left(1 + d^2 + e^2\right)^{\frac{3}{2}}} \quad (5)$$

Mesh's phase models [2], finally, specified geometry's type and changes 3D rough points' set into a direct surface. The produced result is a, visually, more intuitive and realistic representation, (Figs. 24, 25, 29, 30).

This experimentation has been particularly long and difficult because of the presence of shade zones on surveyed object with the consequent unevenness presence [16]; that has involved the necessity to apply these algorithms in almost punctual way and exclusively to small zones of the structure. It is possible, moreover, to export the so resulting model in vectorial way to query in CAD's environment (Figs. 26, 31), or to develop other elaborations in order to correct any errors and empty spaces of interpretation, and to cloth it with particular textures in order to reproduce the reality with fidelity more and more possible; if it's necessary it's possible, moreover, to obtain, in automated way, plans and sections of model, useful for probing or following analysis and investigations.

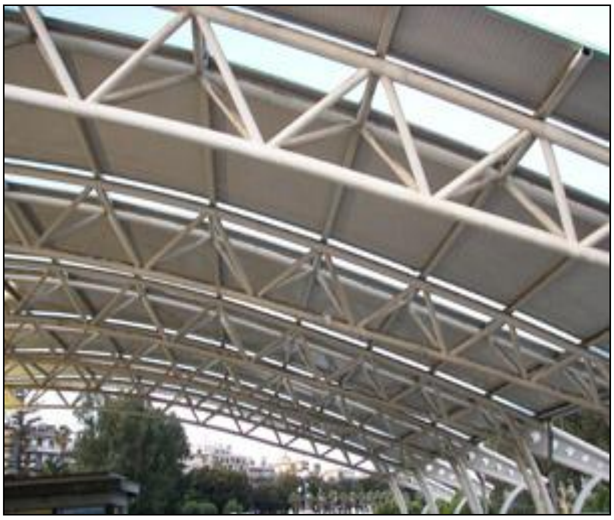

Fig.21: Cover of structure, object of experimentation

Fig.22: Portion of structure, object of experimentation

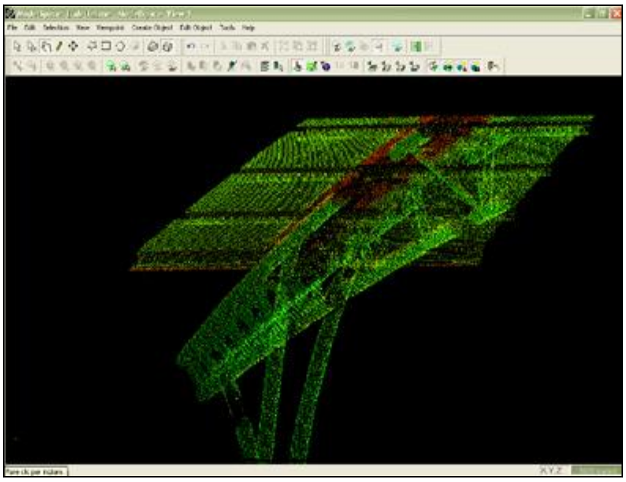

Fig.23 Cloud of points of examined object's structure

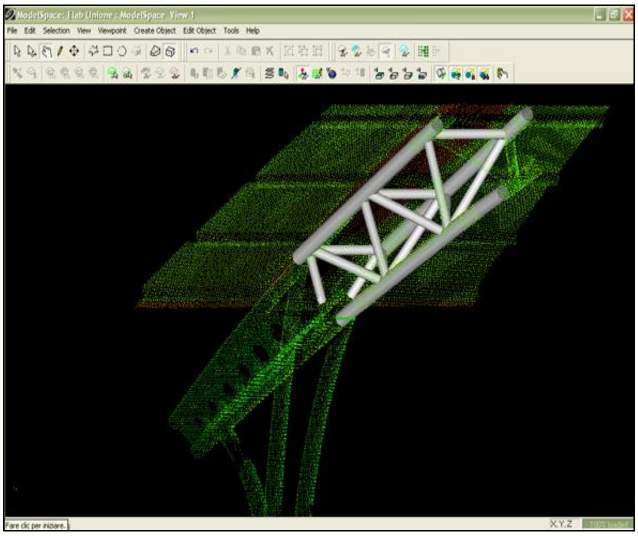

Fig.24: Application of best-fitting algorithms

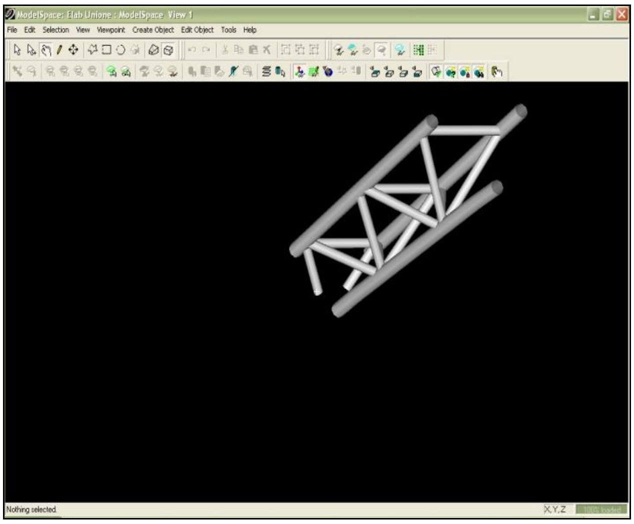

Fig.25: Mesh's model produced

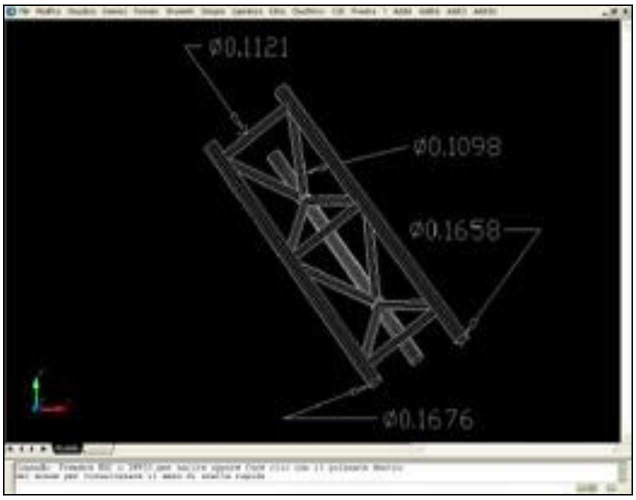


Fig.26: Model vector in CAD environment.

Fig.27: Portion of pillar, object of testing

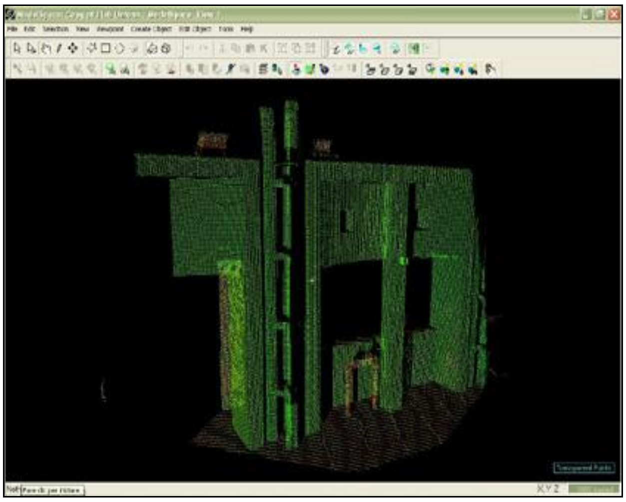

Fig.28: Cloud of points of pillar

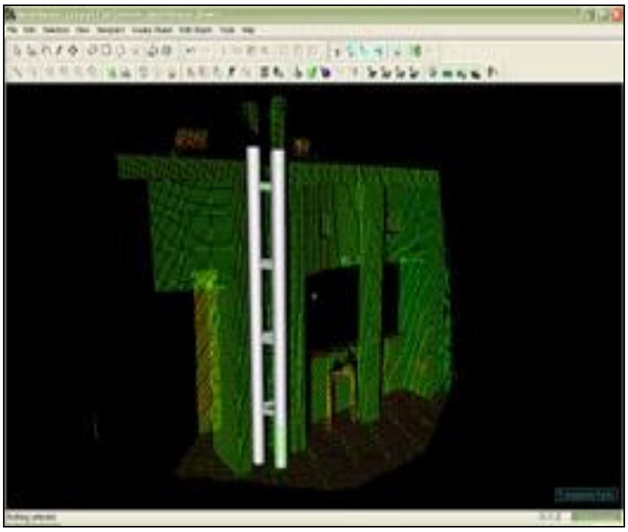

Fig.29: Application of best-fitting algorithms on a pillar

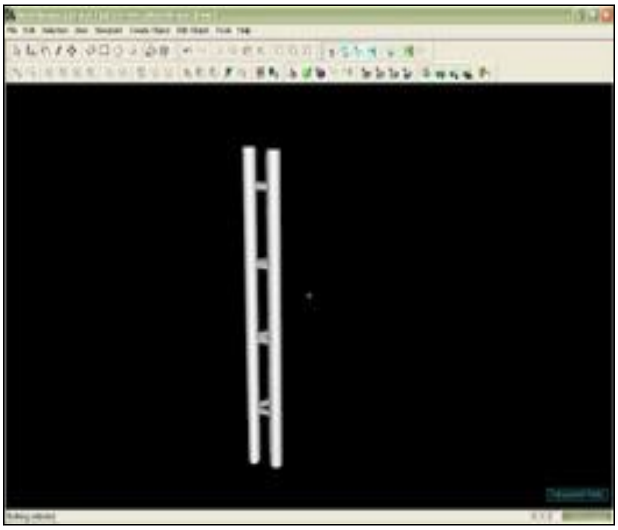

Fig.30: Mesh model of the pillar

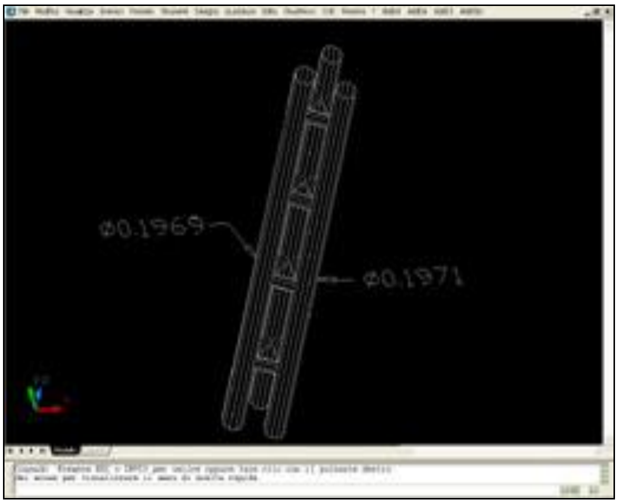


Fig.31: Model vector of the pillar in CAD environment

Obtained the model vector, we made a test of accuracy by comparing the measures from the vector format with the effects on various elements of the structure by means of traditional metrics.
The precision obtained, as shown in the following tables, it is reasonable for structural applications (Table 3).
In particular, we found a better reliability of the measures against the elements vertical and horizontal tubular than oblique, difference, however lower, probably due to the presence of shadow cones produced by other elements of the structure.

| ELEMENT | Measure relief from metric (average) | Measurement by laser scanner (average value) | Sqm |
|---|---|---|---|
| Pillars | cm 20,2 | cm 19,7 | 0,3 |
| Currents | cm 16,2 | cm 16,7 | 0,3 |
| Diagonal | cm 10,2 | cm 11,0 | 0,4 |
| Strut | cm 10,2 | cm 11,2 | 0,5 |

Table 3: Comparison on Precision

## 4 Conclusions

The present work, result of a research's experience developed from the Geomatica's laboratory of Engineer's Faculty of University "Mediterranea" of studies of Reggio Calabria (ITALY), has marked the potentiality of this technology when, for divulgation's purposes, is necessary rapidity of acquisition and usability of information, but also precision and accuracy of the result.

In such sense, it has been possible to appreciate the survey's speed due to the automated procedures; as well as the usability of the information obtained for further processing in a CAD and modeling / structural analysis; on the contrary it has noticed the remarkable work necessary to the elaboration of the data, above all as regards the use of the algorithms of best-fitting, which still need, again in authors' opinion, a wide use of local "manual" procedures and not still completely automated.

The advantage, therefore, in terms of time and cost of use of such technology, must be suitably evaluated according to the result to be achieved.

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