THE USE OF 3D LASER POINT TECHNOLOGIES FOR MONITORING HISTORICAL AND ARCHITECTURAL STRUCTURES

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Abstract: *Historical buildings play an important role in cultural heritage scenario: their main value is due overall to age, artistic and structural features and to surrounding environment.*
Repair and maintenance of historical architecture includes reinforcement of configuration, repair of figure and so on. All these need surveying information and precise determinations. The 3D laser scanning technology is one of the important techniques methods to acquire spatial data. It scans the architecture point by point quickly; registers and joints point clouds to simulate the shape by computer; reconstructs 3D model accurately finally. It also produces construction drawing including ichnography, elevation, and cutaway. In addition, detail structure and vignette can be got by close-range photogrammetry method, which produces the orthoimage and linear drawing.
The paper presents the measurements and representations of 3D laser scanning technologies over historical buildings in city of Timisoara.

Key words: *Building-survey, Monitoring, Preservation, Laser-technologies, 3D model, representation*

1. Introduction

Timisoara, the city with the most historical buildings in Romania, has a large project of rehabilitation and economic revitalization of historical districts. This program of rehabilitation of buildings does not only their outer coating. The program is more complex, covers more components, such as strengthening and repair of buildings (structures strengthen the resistance of the building, restoration of the roof where applicable), improved interior comfort, (replacement of windows, fitting with the minimum utility necessary) and improving interior and exterior appearance (restoration of the ornaments and particularly facades, architectural style and reconstruct the original color of the building).

One of the most ancient buildings is "**The old fortress"** which was built of soil, stone, brick and oak (jig). In the XI-th century, in the year 1052 the perimeter of the old fortress was where today's Palace Theater and Liberty Square[1].

"The new fortress", modern, much larger, was built between 1723-1765. Fundamental stone was placed on 25 April 1723 in the city under the leadership personalities Governor Mercy. The entire construction of fortifications cost 20 million Austrian florins. The great work of eighteenth century was the fortress of Timisoara. Construction of the castle begins in 1723 requiring the demolition of the neighborhood "Palanca Mica".

Speaking about reverse engineering we can say that "Reverse engineering is a process to achieve understanding of the structure and interrelationships of a subject system. It is the goal of reverse engineering to create representations that document the subject and facilitate our understanding of it – what it is, how it works, and how it does not work."

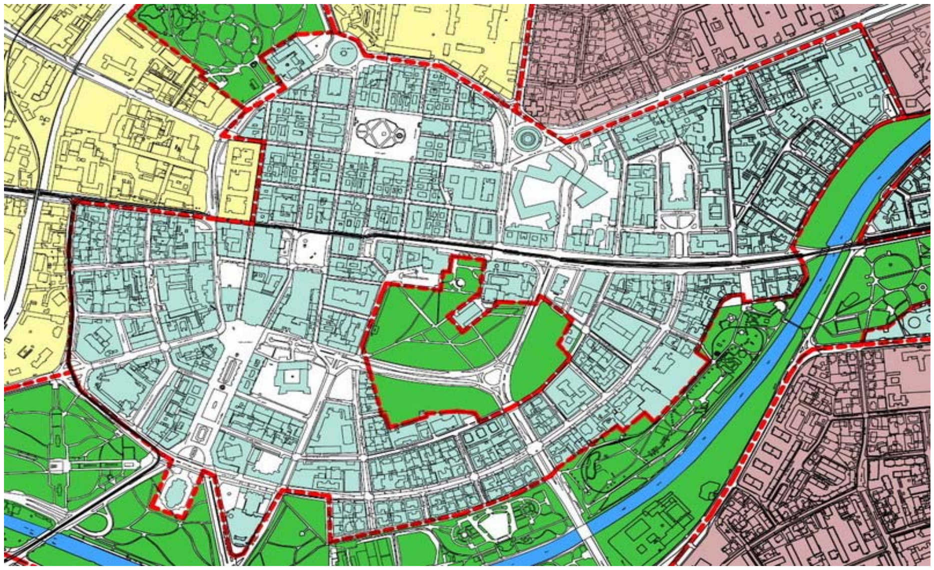

Fig. 1. Representation of historical area

2. The 2D-3D representation

The investigation approach depends not only on the geometric features of the object, but also on the way of representation; this one can be limited to 2D vector CAD drawings (elevations, profiles and sections), or it can add 2D raster descriptions (facades rectifications and orthoimages) and 3D representation after the first measurements (Fig. 2,). Geometric data acquisition develops a building model in an absolute reference system: this is achieved thanks to technologies based on *pre-selected points* measurement, such as surveying and photogrammetry, or related to *random points*, as performed by laser scanning. Usually, acquisition regards a spatial sequence of *object-point*, mostly without control and with precision related to the sensor quality and resolution (linear and angular), such as in surveying measurements, in off-line photogrammetric systems and in laser scanner technologies; on-line photogrammetric systems (stereo-vision) also allow *object-lines* extraction from images.

Building knowledge, useful both for its maintenance and safety, can be well supported by a spatial model, thanks to its better capability of communication, design representation and employment inside GIS environments. 3D visualization, if compared to 2D one, provides a more complete and effective tool for building investigation, which can start from each point of view, both for planimetric data (plan and horizontal profiles) and altimetric ones (vertical sections), and for wall geometry.

Before scanning, we should inspect environment nearby and confirm the number of scan stations, station position and also the controlling targets.

The confidence level of the model quality by the following equation:

$$q = 1 - \frac{p}{d} \tag{1}$$

where: p - object grid step (linear resolution);

d - minimal dimension of recognizable details.

In our case we used the scan station for two different propose as follows: on the ground and underground. In this paper the authors present studies and results for scanning on the ground. Scan the building and acquire amounts of 3D points, which is called point cloud. Register different stations of point cloud, triangulate, fit surface and then reconstruct the 3D model.

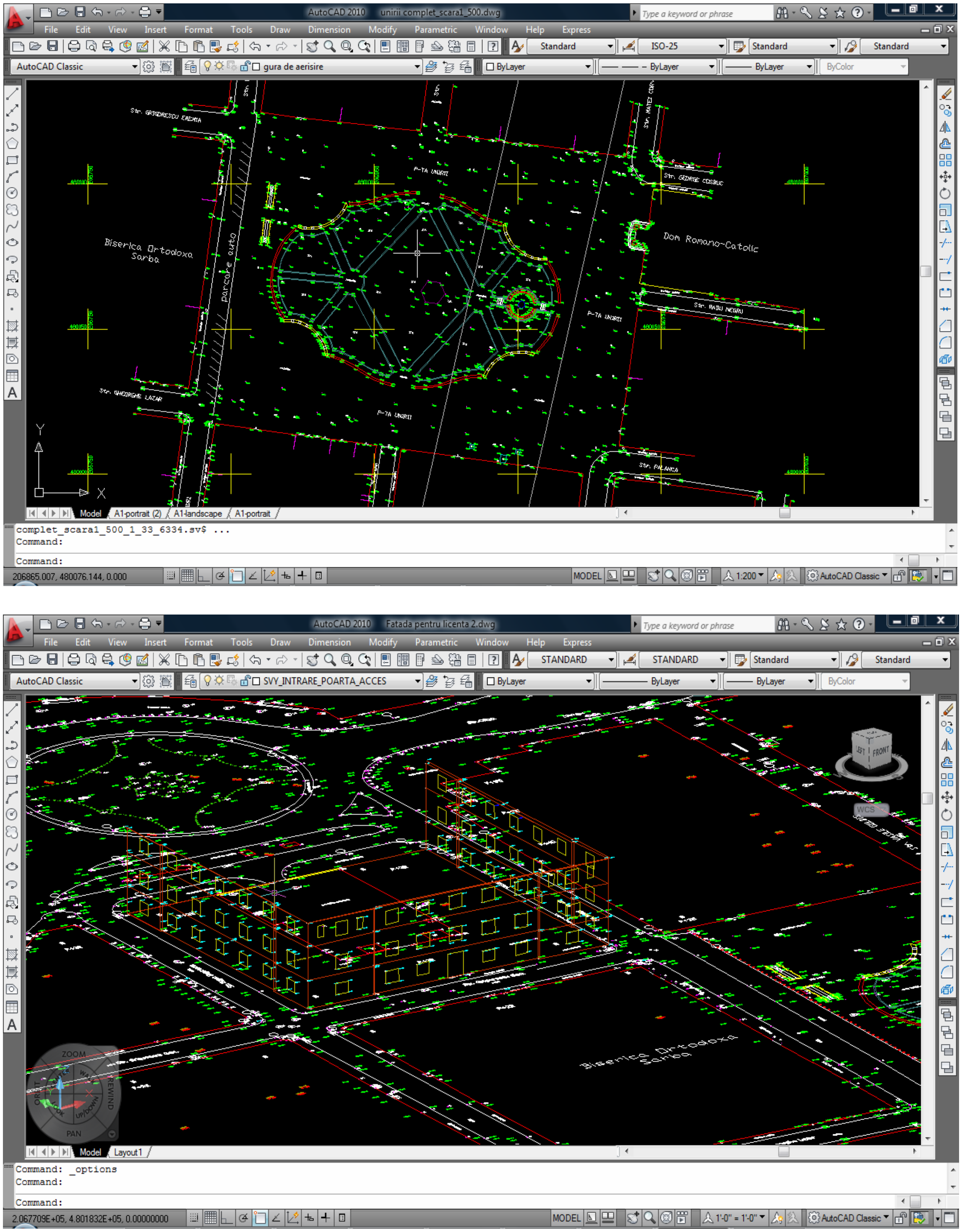

Fig. 2.Difference between 2D and 3D representation

Modeling process includes several steps as follows:

- <u>Data acquisition</u>

Acquire 3D coordinates on the object surface by 3D laser scanner. Besides, geometry position, density of point cloud and image information can be obtained.

- Data registration

In most cases it's impossible to capture the whole object with one scan. So it need scan from different stations. Data registration is to put all point cloud together by coordinate transform.

- Data preprocessing

This process involves data evaluation and filtering. Data evaluation is to find skipped and repeated area when scanning and decide whether to measure again. Data filtering is to reduce noise, smooth noise and resample data.

- Surface fitting

The purpose of surface fitting is to reconstruct a concise and accurate surface. It cannot fit the complex free-surface with only one. Hence segment data to dissimilar areas is combined and used to fit each surface, then joint to a whole one.

- Products producing

The 3D model is constructed based on surface and feature. It can produce ichnography, elevation, and cutaway. After scanning, point cloud is transmitted to work space and modelling under software of reverse engineering. Generally speaking, The 3D modeling includes point cloud, polygon and surface, totally three phases.

- Point cloud phase

Nine point cloud of different station are scanned outside the building. Data registration can transform them to the same coordinate system and obtain registered 3D point cloud (Fig. 3.). Therefore point cloud is under the same coordinate system. The other is to make use of mathematical arithmetic such as quaternion, six-parameters, iterative closest point (ICP), geometric feature constrained (GFC) registration and so on.

- Polygon phase

(1) Wipe off fragmentary polygons

We call the polygon that doesn't intersect with main part or that is interlaced "fragmentary polygon". Fragment wiping off in software can only wipe off the fragmentary polygons which don't intersect with main part, while the interlaced ones must be wiped off manually. But the holes after deleting these polygons should be filled.

(2) Fill holes

The number of holes depends on the data integrality and the number of fragmentary polygons. The principle of filling holes in software is based on curvature around hole. Smaller the hole is or clearer the boundary is, higher the accuracy will be. When filling holes, if some fragmentary polygons are involved, we should wipe off the fragmentary polygons first. Actually, filling holes creates some new fragmentary polygons.

- Surface phase

(1) Construct patches

The pivotal step of constructing patches is patch partition, which is based on surface analyses. Patches should not be divided too small. Otherwise the surface will be too fragmentized to continue following steps. Certainly, patches should not be divided too large, otherwise the quality of surface will be bad since it is hard to capture the shape of point cloud. Commonly, patches, where many characters are, are many and minute, and vice versa.

(2) Construct grids

When we finish editing patches, run "construct grids". The grids can be made symmetrical and coherent artificially likewise. In general, denser the grids are high accuracy the surface has. Otherwise, the data file will be too large to be convenient.

- Export file

We can run 3D compare between surface and point cloud after 3D modeling Import the model to other software after satisfying precision and producing CAD entity model.

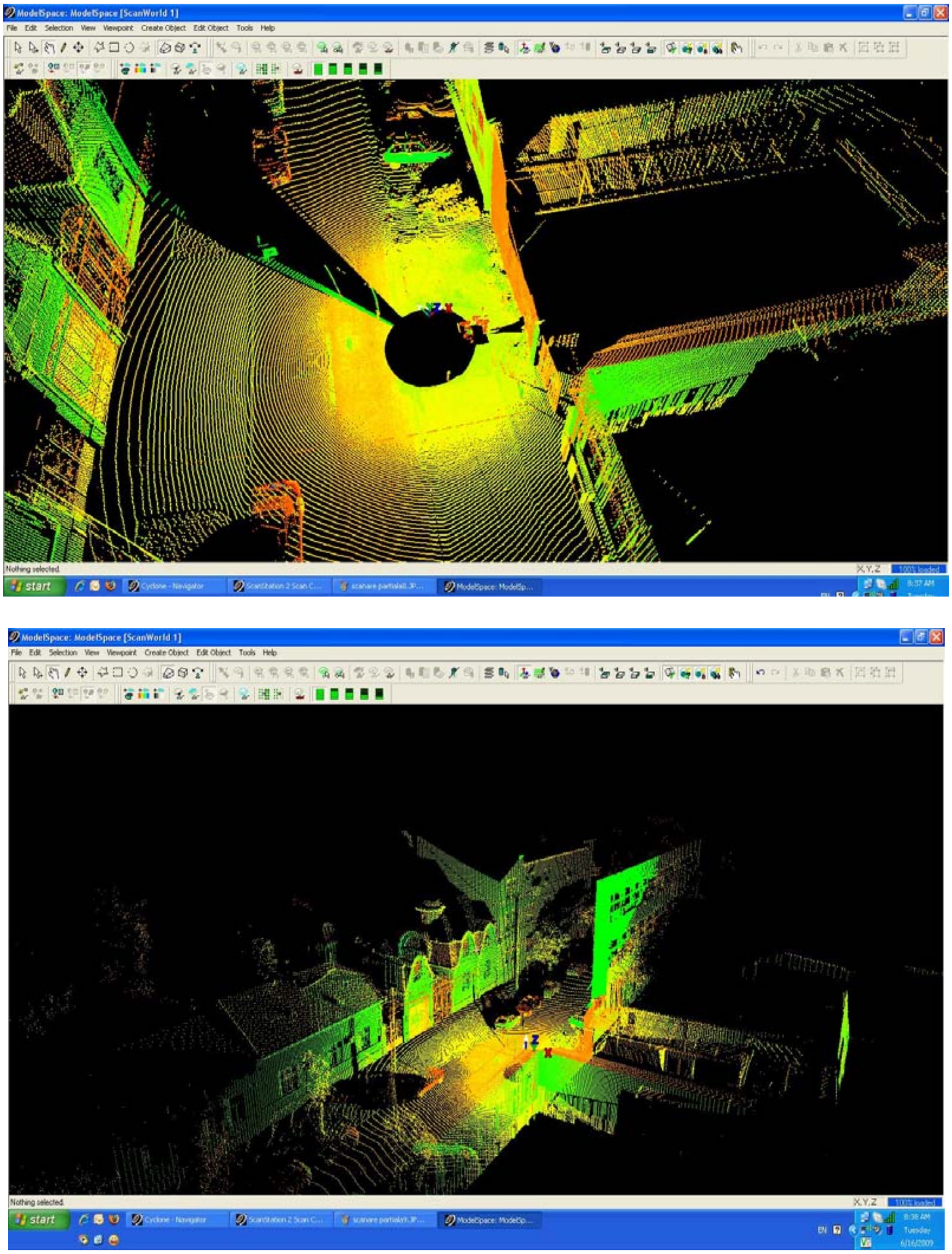

Fig. 3. Partial and total scan

3. Detail collections by close-range photogrammetry

Generally speaking, 3D model reconstructed by scan data has no texture. Besides, scan data can’t keep the details well especially such as detail structure and texture. For detail structure or special areas who need special treatment we can take use of close-range photogrammetry method, which produces the orthoimage and linear drawing.

As we all know, it’s hard to dispose controlling points around every interested areas. Because not only it costs more time but also sometimes it’s impossible to dispose controlling points. The product we need is only the exact scale but not the absolute position. So we choose linear character to rectify image of plane that we chosen.

Image rectifying based on parallel it can be seen in figure 4:

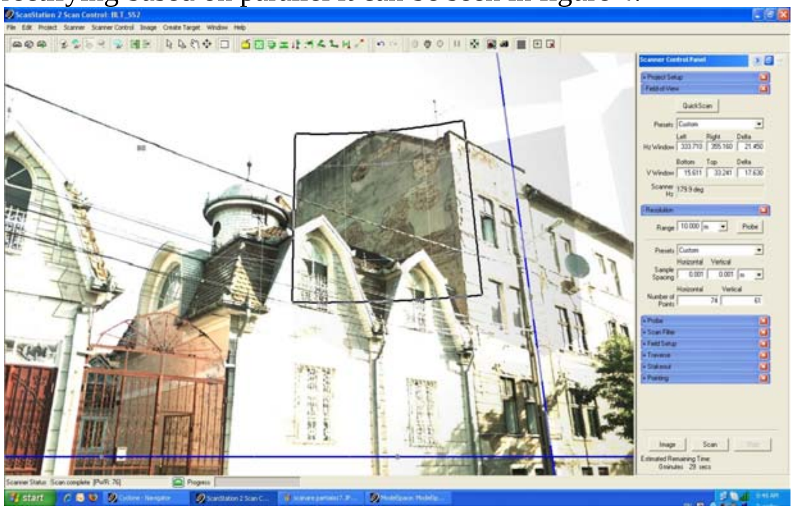

Fig. 4. Image rectifying the plane of detail

In figure 5, it's show rectifying process. Firstly, we define two parallels in direction X, Y; secondly we calculate angles of exterior orientation elements; then measure two distances in direction X, Y and calculate scale coefficient; at last, rectify image.

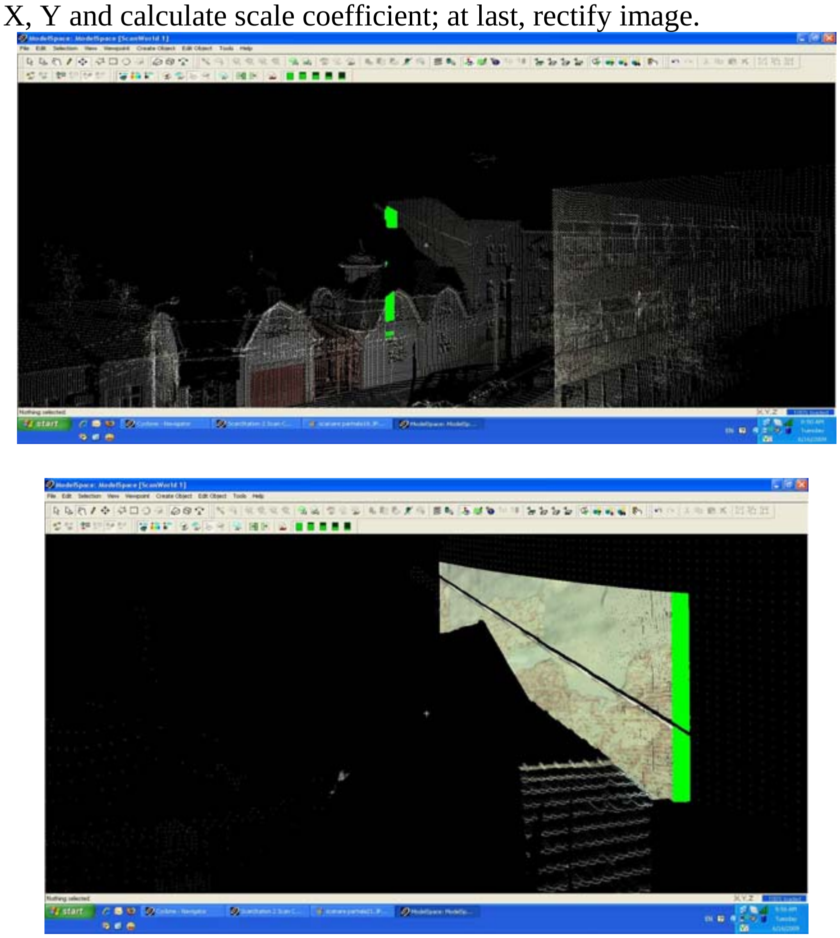

Fig. 5. Detail of interested area

Another example of details scanning, is measuring points with density of 1 mm for a specific window on a building (figure 6). It can be observed how accurate scanning technology plays a clear and precise user requirement.

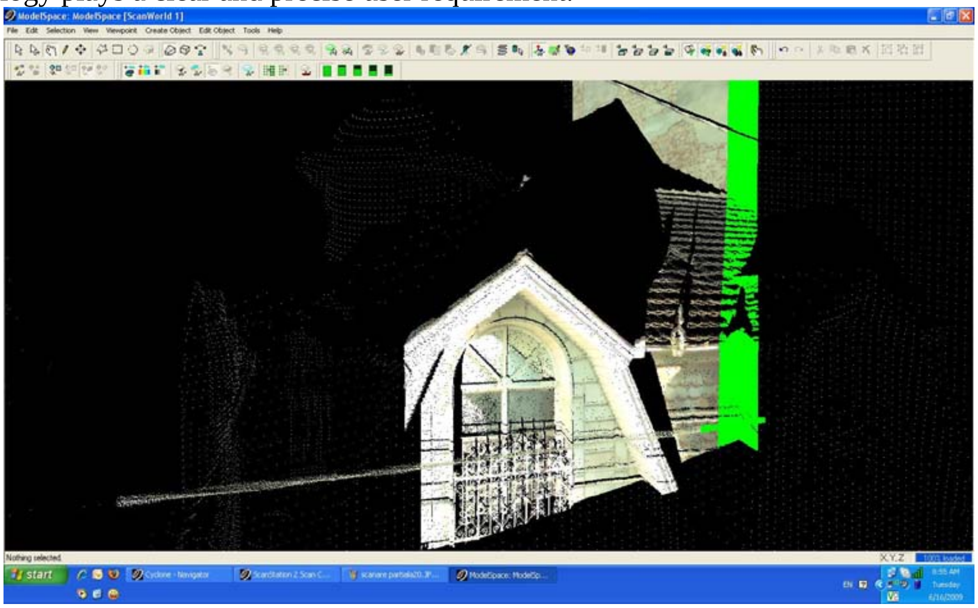

Fig. 6. Window details with 1 mm points accurate

4. Conclusions

The 3D laser scanning technology can acquire 3D point cloud quickly with high accuracy. This meets the needs of historical architecture surveying and protection. 3D laser scanning technology can replace traditional measuring methods completely in historical architecture surveying. 3D point cloud can be gained by laser scanner, then construct the 3D model.

In addition, detail structure can be got by close-range photogrammetry method, which produces the orthoimage and linear drawing. Surveying of Historical architecture based on 3D laser scanning technology can not only reduce field work, improve efficiency but also provide different kinds of products such as 3D model, CAD construction drawing and so on. 3D laser scanner is growing towards high speed, high accuracy, large range and multi-information etc at present. All these will impulse laser scanning application to historical architecture surveying and protection.

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