ON THE INTEGRATED USE OF LASER-SCANNING AND DIGITAL PHOTOGRAMMETRY APPLIED TO AN ARCHAEOLOGICAL SITE

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ABSTRACT:

At the end of 2003 the excavations for constructing the Piazza Municipio station of a new underground line has digged out important findings of Naples ancient times whose trace could be found only in legends and old paintings; in particular, two wooden ships of II century A.D. and Augustan ruins of V century A.D. were discovered. Lackink a general cartography of the city of Naples dating back to the 1400, it has been decided to reproduce the complete map of the town centre in the light of the new findings and to compare it with the "Topographic map of the city of Naples and of his surroundings,", created by Giovanni Carafa, Duke of Nola, and posthumously published in 1775. The main objective of our work has been the survey of a wide surface standing below the moat surrounding Maschio Angioino, the king's castle, including a tunnel to redoubts and army magazines. This has been done by integrating the laser scanning technique with digital photogrammetry in order to obtain a model fulfilling the high precision standards required by the aesthetic quality of the site and adequate for being divulged for advertisement and scientific research.

1. INTRODUCTION

Three-dimensional survey represents the pivotal technique for the detection and the mapping of historical assets and archeological sites; as a matter of fact their geometrical knowledege is fundamental to its monitoring and preservation, as well as to the creation of databases. To this end it is necessary to integrate 3D model obtained by using laser scanners or digital photogrammetry so as to dispose of digital models useful to reconstruct the territory morphology.

Figure 1. Overview of the site, july 2006

An application of these concepts is here proposed with reference to some recent archaelogical findings in the centre of Naples digged out at the end of 2003 during the excavations for constructing the Piazza Municipio station of a new underground line; specifically, two wooden ships of II century A.D. and Augustan ruins of V century A.D. were discovered. It seems, indeed, that the sea flowed close to Maschio Angioino, the king's castle, creating a peaceful bay useful for trade and commerce. During the following centuries the seashore advanced, due to washing away and landslides, so that a street was built during the VI century. Further studies have revealed the existence of several concentric moats surrounding Maschio Angioino as well as the existence of factories and powder magazines (De Seta, 1969). Five centuries ago the sea-view of the castle presented white battlements above the counterscarps lying at the very bottom of the medieval towers. Later on such towers, erected during the Aragonese domination, were abandoned and their interior, mainly constituted of rooms and underground ramps, was filled up with discarded material. Currently, the combined use of laser scanner technology and of the traditional methodologies of survey turns out to be quite efficient for the 3D digital reconstruction of complex historical buildings with great metrical precision. Specifically, laser scanners provide a digital model of the surface by means of which one can produce multilevel 3D meshes that allow one to achieve, as it will be illustrated in the sequel, orthophotos having different levels of resolution.

2. LASER SCAN OF THE SITE

2.1 Description of the archaelogical site

The archaeological site is exstremely complex and articulated, mainly for the presence of different wall rings surrounding the castle, each belonging to different periods. The highest and most external ones date back to the spanish domain whereas the lowest ones go back to Greek and Roman times. During the

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excavation of an area of 60x25 mt in plan and 50 mt in height it has been found, beneath the concentric rings of masonry fortifications, a 10x60 mt area, completely unknown, made of communication trenches and a tunnel. Probably, during the spanish domain it represented a direct link between "Castel Nuovo" (New Castle) and the defence garrison and powder magazines. The internal surface of the vault is of particular interest as well as the area on the backyard used as military depots. The survey of the area has been carried out by using a Leica HDS3000 laser scanner characterized by a ± 6mm resolution at a maximum distance of 250 metres. In order to consider a common reference frame, a topographic net has been established by using a total station Leica TCPR1205. Moreover, a metric camera Canon EOS 5D, with a 10 Mpixel sensor, has been used to obtain high resolution photogrammetric images to be integrated with the laser scanned data. The sensor has been placed in different positions since a refined modelling of the surveyed surfaces has been made possible only with a suitably high scanning density. In the sequel we detail the main results of the acquisition procedure which lasted two days.

2.2 Working stages

An accurate reconnaissance of the site and planning of the working stages has been preliminarily made in order to achieve a precise survey. The operative procedure which have been adopted can be summed up as follows:
1. set up of the topographic net;
2. positioning of targets and of additional check points;
3. laser scannings;
4. high precision photogrammetric snapshots.

The scanner has been located in various positions and suitably oriented in order to get rid of the problems linked to shadow lines and obstacles such as masonry walls, embankments and additional manufacts.

2.3 Planning of the acquisition stage

The acquisition has been carried out considering the following aspects:
1. laser instrument model;
2. inspecting area;
3. dimension and geometry;
4. environmental context in which the object to be scanned is positioned

2.4 Data acquisition

Data acquisition consisted of three different surveys: plano-altimetric points by means of a total station, laser scanning data and, only in specific points, integration with digital photogrammetric data. Both the preliminary acquisition and the postprocessing have been performed by the Cyclone 5.6 software. The laser scanner has been located in ten station points: four of them inside and six outside the tunnel; three topographic survey points for the total station and five photogrammetric snapshots of pieces of masonry and of textured walls. Moreover, the Leica TCR1205 total station has been used to provide the same reference frame both for the laser scanner data and for photogrammetric data.

2.5 Laser scanner survey

Due to the complexity of the object to survey the complete model has been reconstructed by several scans; thus, it has been necessary to plan a set of scannings from different views. Each

scan is related to its own referene frame having origin in the centre of the laser scanner; hence, to obtain a complete three-dimensional model all the scans must be oriented in accordance with a common reference frame. This alignment has been ensured by an accurate positioning of the reflective targets choosen as function of the laser scanner resolution and by selecting at least three corresponding points in two contiguous scans (nature or artificial elements). A typical spatial distribution of markers is illustrated in the figure 2.
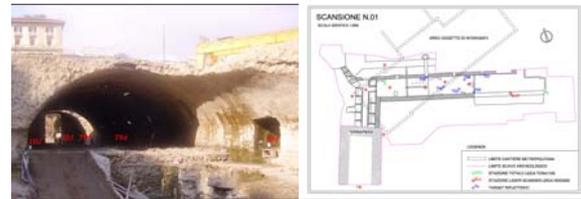
Figure 2. Laser scanner positioning

Moreover during the acquisition data, the scanning of the reflective targets allows for the geo-referencing in accordance with an absolute reference system. The choice of the targets depends on the angle resolution imposed in the scanning, the range between the object and the laser scanner, the laser ray divergence, reflectance so to be more easily visible by the operator and software Cyclone 5.6. The operations related to the instrumental set up and scanning require, on the average, 10 and 20-40 minutes respectively, with a resolution oscillating between 2.7 cm x 2.5 cm depending on the distance and the geometry of the surface to scan. This setup allows for an acquisition of 1000 points/sec. During the scanning the software supplies a 3D model of the sensed points with their reflectance, according a chromatic scale (Hadjri, 2003; Ruther *et al.*, 2003; Warden, 1999). Station SL01 has been placed outside the vault, on the top of the remains of an ancient masonry, in such a way to have a wider view in the survey of the details and of the targets. To obtain a complete scanning of the area the calibration of the acquisition parameters has been optimized with a resolution of 1.3 cm x 0.5 cm, a value which guarantees a good optical quality, metric precision and, in addition, scanning angles equal to 300° in a horizontal and 70° in a vertical plane. The markers' coordinates and their relative heights are reported in Table 1.

POINT	X [m]	Y [m]	Z [m]	RANGE[m]
T01	-17,1482	6,6205	-0,6451	18,3928
T02	-20,1599	-3,9511	-0,8716	20,5652
T03	-27,3409	-3,4582	-0,6152	27,5655
T04	-30,6837	2,1126	-0,9973	30,7715
T05	-33,6652	-3,0652	-0,669	33,8109
T06	-45,2706	-0,4365	-0,5576	45,2752

Table 1. Markers' coordinates

The remaining topographic stations are placed inside the vault, at the end of the tunnel and at the street level.

2.6 Photogrammetric survey

The last stage of the survey operations has concerned the acquisition of a set of photograms in order to integrate them with laser scans. Globally, there have been carried out 10 digital high-resolution photogrammetic acquisition of the masonry and of its texture characterized by a range between the object and

the focusing plane variable between 1,50 and 3 meters (Ioannidis *et al.*, 2005). The operations have been performed very quickly and the digital images have been processed by the Photomodeler software, suitably set with the parameters of the camera and the internal orientation. The result has been an image recorded in the bmp format which can be imported in the Autocad software and superimposed to the DTM obtained by the laser scanning survey. For what concerns the integation of the two techniques the following issues need to be properly taken into account:

1. the most significant problem for the precision of the results is represented by the necessity of obtaining crisp images sharing a common orientation with the laser scan;
2. a common distance of the focusing plane as function of the surveyed object.
3. ortogonality of the snapshot with respect to the object.

The comparison with laser data has also allowed us to perform a qualitative control of the results as well as the chromatic restitution of the surveyed surface (Warden, 1999).

Figure 3. Masonry processed by the Photomodeler software

3. DATA ELABORATION

3.1 Registration of the point clouds

We remind that any 3D model of the object (point cloud) carried out by a different scanning point is expressed in a local reference frame, changing with the point, centered on the instrument and arbitrarily oriented. Accordingly, the models constituting the survey are independent one another and do not share any predetermined geometrical relationship.
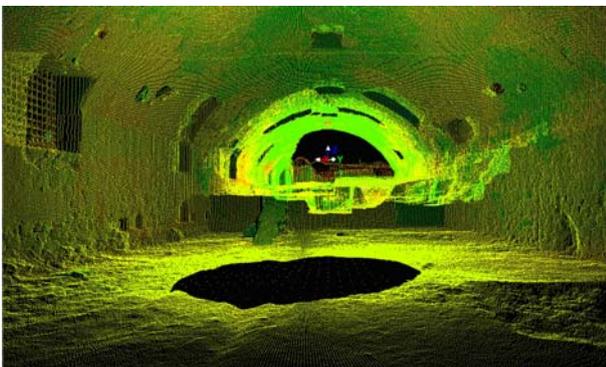

Figure 4 - Partial 3D model obtained by the station SL01inside the tunnel

Consequently, the first problem to handle is to evaluate, analitically or instrumentally, the parameters of displacement and rotation which allow one to express all the scannings within the same reference frame; in this way one can mathematically assemble the scan of the object by aligning the parts in which it has been subdivided. This operation is termed *registration* that is optimal alignment of three-dimensional objects (Beinat, 2006; Ioannidis *et al.*, 2005).

Identification and accurate measurement of the corresponding points in the 3D models
Manual identification of the correspondences; algorithm for labeling
Automatic alignment by means of a compatibility check between surveyed surfaces; ICP model
Geo-referencing of the 3D model

Table 2. Separate stages of the alignment procedure

3.2 Filtering of the point clouds

During the processing of the model, non systematic or erroneuos points are automatically removed; additional points are manually checked, and possibly removed, in delicate parts of the object when the software can fail. Furthermore, the automatic removal of the points, even of the redundant ones, is not always recommended since as the points become thinner important details can be missed, what deteriorates the quality of the model. The attemp to automatically remove points by the *range gate* criterion, that is to accept only the points lying within a determined distance/surface to be defined as function of the maximum dimensions of the object, exhibits some drawbacks since cancels out points of the cloud which are fundamental for the sharpness and the generation of the 3D model. On the contrary, the manual approach allows one to eliminate the noise of the useless data, see Figures 5 and 6.
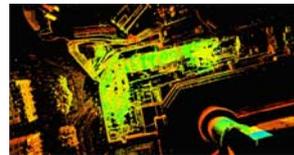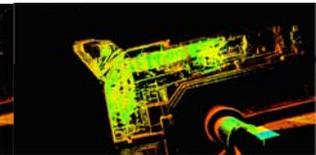

Figure 5   Figure 6

Once the points representing the object have been selected, the TIN (Triangulated Irregular Net) surface passing through them is generated and the DSM (Digital Surface Model) is obtained. It can be further improved by means of suitable smoothing oerations and of elimination of little triangles (Andreoni & Pinto, 2006; Visintini *et al.*, 2005).

3.3 Triangulation process

The number of triangles used in the model are of the order of millions; however, in spite of this, the triangulation process unavoidobly produces a 3D model containing some missing parts, holes, superpositions and so on. This phenomenon is extremely frequent in three-dimensional modelling and, to date, several complex procedures have been proposed in the literature (Lillesand & Kiefer, 1994) to alleviate them. Even if a given surface is scanned several times by considering differently positioned scanning angles, occlusions may prevent the laser ray to reach the deepest slits. Missing parts of the object can also be caused by the low level of reflectivity, by constraints

imposed by the surroundings on the plan positioning of the laser scanner or, more simply, by the impossibility of getting some views of the object, see Figures 7 and 8, (Brukamp, 2005; Fernández *et al.*, 2005; Ioannidis *et al.*, 2005; Visintini *et al.*, 2005; Andreoni & Pinto, 2006).
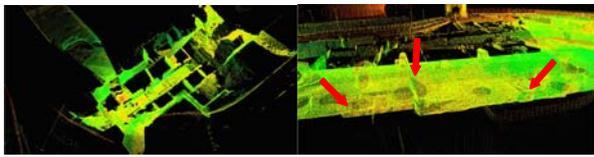

Figure 7   Figure 8

In order to fill in the missing parts, it is usually adopted an interpolation procedure, that is a mathematical procedure which estimates a set of coordinates in order to evaluate intermediate values. The generation of triangulated surfaces or meshes has been obtained by the Cyclone software starting from the coordinates of the laser points recorded in the ASCII format which employes three basic primitives: point, polygon and surface. The production of clouds is determined by the simple visualization of the scanned data, the composition of the polygon by means of a triangulation and, finally, the creation of surfaces by adopting NURBS, non uniform rational B-splines.

3.4   Occlusion of holes

The methods which are adopted in this case usually involve the interpolation of the original model according to predetermined sets of figures, shapes and spheres whose surface is made to evolve so as to fit approximatively data or the measure of the set of three-dimensional data, see Figure 9.
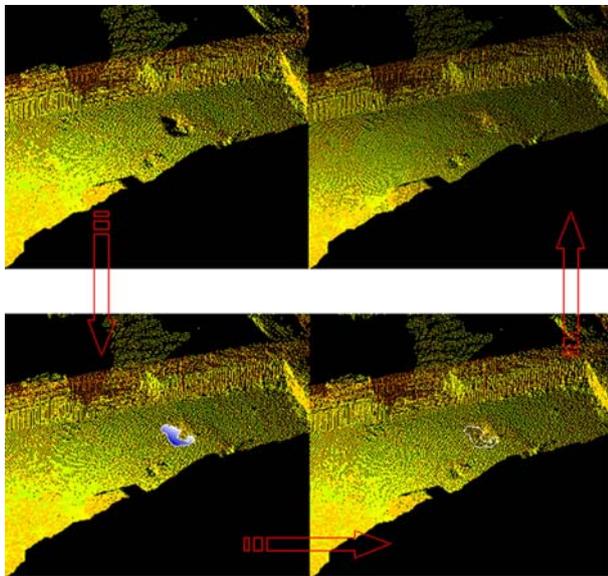

Figure 9 - Process of holes occlusion

However, interpolation can fail for data affected by excessive noise, for instance if this is almost equal to the density of the sample in the sense that the whole surface is sensibly disturbed. Clearly, such techniques are applicable mainly whenever it is required a surface confined to a small volume. A simple solution to this problem can be the use of additional data such as points or triangles which connect points belonging to existing surfaces. Based on this idea, the use of photogrammetric data

can be used to define the topology of the object and verify the correctness of the scanned object (Fernández *et al.*, 2005; Hadjri, 2003; Yastikli *et al.*, 2003).

3.5 Output of three-dimensional modelling: plans, views, sections and assonometric views

The step following the generation of the three-dimensional model is to properly manage it, in particular for what concerns its visualization. In this respect laser scanned data can be managed in several ways. Usually, the output allows one to handle model at different stages of sophistication as function of its format: this can be VRML (virtual reality modelling language), dxf, txt, ASCII and AVI if animations are required. Initially, the model is handled through the VRML format which allows one a rapid visualization. This feature does not allow for a metric representation of reality but, nonetheless, it represents an efficient way to achieve economically a thorough documentation of the scanned object. Furthermore, the VRML allows for a 3D navigation and graphical output such as plans, views, sections as well as saving of assonometric and perspective views.
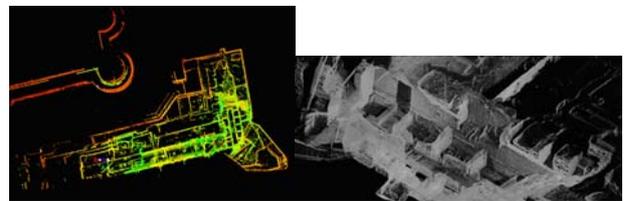

Figure 10   Figure 11
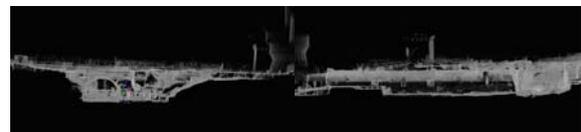

Figure 12   Figure 13
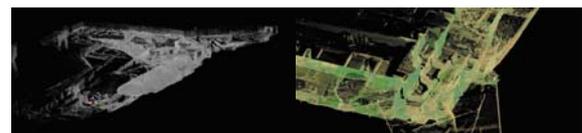
Figure 14 - Assonometric view of the site
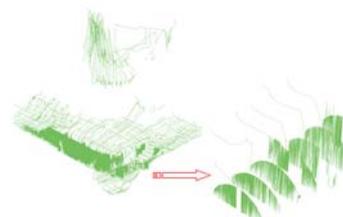
Figure 15 - From the generation of transversal and longitudinal sections to the visualization of elements of the tunnel

Such an output allows for the generation of a high precision DTM for controlling the territory and the areas surrounding the archaeological site (Brukamp, 2005; Fernández *et al.*, 2005;

Hadjri, 2003; Ioannidis *et al.*, 2005; Murphy *et al.* , 2005). Accordingly, a number of computational–graphics products are automatically obtained.
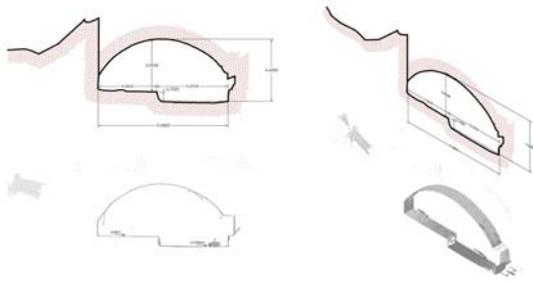

Figure 16 - Transversal section and assonometric view of the tunnel, of the point-cloud and of the dwg

4. INTEGRATION OF THE LASER SCANNING TECHNIQUE WITH DIGITAL PHOTOGRAMMETRY

A descriptive model obtained by a laser scanner still lacks the whole radiometric information. Clearly, disposing of this feature further facilitates the object interpretation since in this way one obtains three-dimensional digital models closely resembling the real ones. In particular the objctive was to check the accuracy of the laser scanned model with respect to the photogrammetric digital models. A correct superposition of photogrammetric images and three-dimensional models useful, e.g., for carrying out measurements, produces a result of great impact and allowing for a variety of additional uses. Thus the elaboration of laser data can produce a basic detailed model of the DSM; conversely, the photogrammetric integration allows one to analyze in detail portions of the object difficult to survey (Achille *et al.*, 2002; García-León *et al.*, 2003; Perfetti *et al.*, 2005; Ruther, 2003; Yastikli *et al.*, 2003).

4.1 Elaboration with the Phtomodeler software

For the case at hand the elaboration with the Photomodeler software is particularly simple since no three-dimensional data are extracted but only coordinates at the end of the calibration procedure, a fundamental task for achieving high precisions. Initially, one highlights the markers, i.e. the points common to the laser scanning and the relevant cartesian coordinates x,y are reported down on the left, see Figure 17.
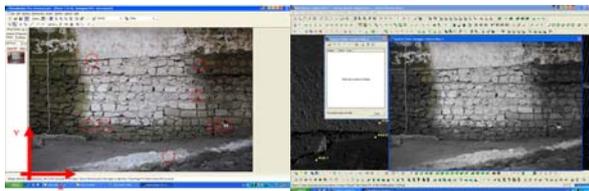

Figure 17   Figure 18

In this way one infers the ranges between pairs of markers from the previous coordinates.

4.2 Integration of laser scanner data with the photogrammetric survey

The analysis of masonry surfaces inside the tunnel has been carried out by integrating the laser scanning and the digital photogrammetric technique. Specifically, the examination of the single photogrammetric image and its fusion with three-dimensional data obtained by the laser scanning survey has permitted a qualitative and metric check. Firstly, photogrammetric image is processed by the Cyclone software and the corresponding points are determined (Dequal *et al.*, 2006; García-León *et al.*, 2003; Koistinen *et al.*, 2001; Perfetti *et al.*, 2005; Sabry, 2005; Warden, 1999). Subsequently the cartesian coordinates x,y,z, in the reference frame having its origin in the center of the instrument, are extrapolated and distances between pairs of markers are determined.

4.3 Test results

Experimental tests have been limited to a small portion of the surface, inside the tunnel, which is characterized by a smooth and regular shape. In particular a quick comparison shows that laser scanner data are particularly dense and cover almost all the particulars of the masonry surface (resolution of 1.5cm x 0.5cm). However, the generated model exhibits a remarkable density of points with lackings limited to small areas. This highlights that the filling of holes generated by the laser scanner by virtue of photogrammetic technique is a valid integration procedure. Geometric information obtained after the Photomodeler processing significantly change for what concerns density and characteristics of data. There is a high density of data in the model produced by the laser scanning which produces the representation of the surface model; on the parallel side an increase of local errors are evidenced.

In the model produced by the Photomodeler software one notices:

a. a few, well defined, points which ensure the correct positioning of the object surfaces;

b. the construction of a 3D model characterized by analytically defined surfaces.

The appearance, within the DSM generated by laser scanning, of shadows make suitable the integration with photogrammetric tecniques; this require greater computing times but provides a complete model, perfectly sticking to reality. Thus, a simple comparison of the two models provides acceptable results with differences ranging from 1,49788E-05 meters to 0,176584511 meters. In other words a close integration between the two techniques has been obtained and a remarkable metric quality. The main advantage of the laser scanner technique is the high density of points obtained in a relatively small amount of time; conversely, photogrammetry is much cheaper and provides radiometric information (Dequal *et al.*, 2006; Fernández *et al.*, 2005; García-León *et al.*, 2003; Ioannidis *et al.*, 2005; Warden, 1999; Yastikli *et al.*, 2003).

5. CONCLUSIONS

The complex nature of archaelogical sites must be necessarily tackled with refined methodologies and approaches which allow the user to obtain models particularly similar to the reality. For what concerns the urbanistic-archtectural heritage it is now possible to merge within a single 3D model metric and digital information of laser and photogrammetric surveys with the historical artistic data reported in maps produced by classical surveys. Their representation can have several aspects (plans, sections, views, assonometries, perspectives), formats (TIN, vectorial, raster, mixed), modalities (static, dynamic) and additional informatic characteristics (interactive, consultable, virtual, ecc). In conclusion, one obtains a unique 3D mdel which describes the current state and the time evolution and can

be of great help in design and restoration; moreover, its simulation can be represented on the model itself (Belardin *et al.*, 2002; Dequal *et al.*, 2006; Fernández *et al.*, Hadjri, 2003; Warden, 1999; Yastikli *et al.*, 2003).
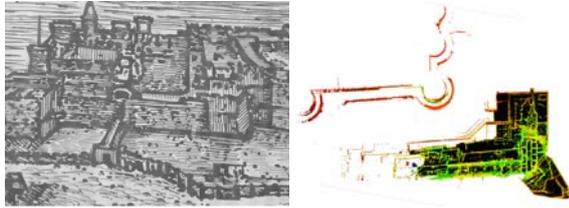

Figure 19 - Comparison between an historical cartography, dated 1700, and the laser generated DTM
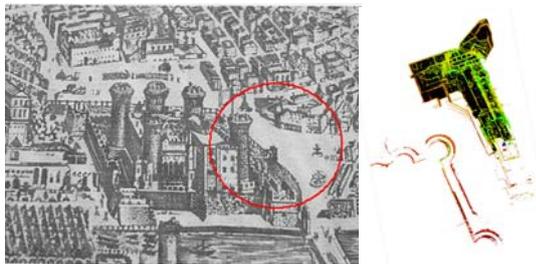
Figure 20 - Comparison between an historical cartography, dated 1700, and the laser generated DTM

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