DOCUMENTATION OF ROMAN EXCAVATIONS BY LASER SCANNING

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Commission V, WG V/2

KEY WORDS: Cultural heritage, Terrestrial laser scanning, 3D modeling, Archeology, Visualization, Documentation technology

ABSTRACT:

Nowadays 3D laserscanned point clouds are used in many fields of sciences. This paper presents a comparison study of the established geodetic technologies and laserscanning. The modern technology allows more details high accuracy, rapid data acquisition, and more realistic new products – such as three dimensional virtual models or textured meshes – or even orthophotos can be easily created. First of all we studied the required archeologic documentation of various excavations and realized that better results, more realistic and detailed documentation can be reached at the same time as with traditional surveys. We developed a mapping process for archeologically relevant objects – ground plans, overviews, brickworks – which is preferred in many cases. In case of roman tessellated pavements or brickwork drawings the documentation process can be shortened, and human resource can be saved using ortophotos or post-processing. Although the post-processing requires time, it is productive and accelerates the work in the excavation field. Three dimensional wireframe models or the point cloud itself help us to draw reconstruction plans or in other applications like creating chronoscope. In every respect, the most important view was that we wanted to get such a documentation, which can present more information than the traditional methods and aims to create a global archeological informational system.

1. INTRODCTION

1.1 General considerations

Laserscanners have found large interest during the past few years among archaeologists. We wanted to prove the usability of this technology and the efficiency compared to conventional geodetic methods or orthophotos. Therefore we scanned the same excavated area, and after the measurements the documentation was made in the office. In most cases, archaeological findings are found during building operations or any other public services that are under constructions. On that score, the archaeologist has no time for documentation. Besides this, in many cases the reconstruction of the ruins is not possible because of the lack of funds or other various reasons, so regularly the ruins to be preserved must be covered after mapping,. We made our experiences in Budapest, in the area of the Aquincum Civil Town. The core of the Civil Town is located around the Museum in the reconstructed ruin park. In the neighbourhood of the ruin park, there are different kind of roman findings and ruins. During our project we co-operated with the archaeologists of the Museum. Because of the aforementioned reasons, the outside excavated area – not including the Museum and the ruin park – is usually available only for short time, so that it is very important to scan every detail and plan the survey comprehensively. The typical objects are 1-2 meter high wall remains, murals, mortal remains, crocks, or mosaics.

1.2 Archaeological survey with laserscanning

The scanning was executed by a Riegl LMS-Z420i terrestrial laserscanner. This type of laserscanner can be used with a 6 Megapixel Nikon D100 camera. Depending on the project, the focal length of the lens can be chosen between 20 or 85 mm. The scanning process allows high-speed 3D measurements. Laserscanners can measure millions of points with a laser beam within a short period of time, and after the scanning automatic colour panoramic scans can be achieved. Table 1 shows the main technical parameters.

Range	2 m up to 1000 m
Repeatability	Up to 4 mm (averaged)
Measurement rate	Up to 8000-12000 points/sec
Accuracy (<50m)	10 mm
Laser wavelength:	Near infrared
Beam divergence	0.25 mrad
Vertical scanning range	0° to 80°
Horizontal scanning range	0° to 360°
Minimum angle step width (vertical)	0.008°
Minimum angle step width (horizontal)	0.01°

Table 1. Technical specification for Riegl LMS-Z420i

In many cases the object has to be scanned from more viewpoints because of hidden areas; so after the scanning process the different scan positions are to be registered into one project coordinate system. To make it easier, we use artificial control points, the so called reflectors. After registration, the measurements were transformed into the Hungarian National Coordinate System (EOV or HD-72). The scanner controller software allows transforming from

the scanner coordinate system into the camera's coordinate system. The camera position and mounting are known during the image acquisition.
Under these circumstances it was a good opportunity to try orthophoto creation. In order to improve the results, it was useful to acquire more series of images with different settings; although the scanner can rotate 360 deg, photos against the sun couldn't be taken. Preferably the orthophotos and the colour pointclouds must be esthetically homogenous.
During the measurement's planning, we took notices of many aspects. In case of nearly orthogonal scanning position, the multiple projections don't really effect. Therefore these positions are favourable; contain more details and less hidden areas.
In every respect the scanning resolution depends on the scanned object and the distance from the scanner. The overview is executed by lower resolution, while the archaeologically important parts, e.g. brickworks by higher one. In a roman era dated excavation the findings are wall ruins, bones, mortal remains, murals. In case of detailed areas the importance of image resolution grows. In optimal case we can measure with 5 mm accuracy but some objects require more details. Due to the high resolution of the acquired images, an orthophoto can contain a lot of information. Making orthophoto is recommended for mapping little objects but it can't work in every cases. In the orthophoto some parts have different luminosity. Sometimes this can lead to false conclusion. Actually our researches focus on the described terrestrial laserscanner; for higher accuracy close-range (object) scanners are suggested.
In our first project in the Aquincum Ruin Park, the aim was to map the wide-ranging reconstructed area. One of the most important features of the surveyed field is having antique wall ruins mostly under the ground. Therefore we can only mapping, check the reconstruction, complete the missing parts and improve the accuracy.. The possibility of panoramic scan has been proved to be useful, reducing the time of measurement, and survey the whole neighbourhood.

1.3 Archaeological documentations

As laserscanning became popular in many fields of science, the archaeological view of the documentation has been examined. The traditional geodetic documentation contains the following drawings:

- Overview of the excavation (scale: M=1:100, 200, 500 etc.),
- Detailed ground plan (scale: M=1:10, 1:20)
- Brickwork drawings (scale 1:10).

The drawings had to be transformed into EOV system,. This transformation allowed the comparison between the different mapping methods. For the map generalization we used the same legend. The documentation can be replaced by an orthophoto. Due to laserscanning, the orthophoto is based on the surface model, so this process results true orthophoto, contrary to traditional orthophotos that only eliminate the perspective distortion of the images..

1.4 Software for data processing and modelling

The control of the measurements and the pre-processing was practically made by the scanner software.
With the usage of reflectors, the scan positions can be transformed into the project coordinate system, and make mounting calibration.
Before colouring the point cloud the images were manipulated to homogenous luminosity and disturbing details were removed. Because both lens are calibrated – the distortion parameters are known – the software can automatically create distortion-free images for orthophotos.
Due to the accuracy, the standard deviation of the measured point cloud is at least 5 mm; consequently the thickness of the pointcloud is at least 1 cm. Applying more scan position, this value grows. In spite of this, the averaging leads to good results. The orthophoto creation with resampling and pointcloud thinning method can get better images. The difference appears mainly in edges.
In order to compute the true orthophoto Matlab was used.
After registration, the removal of the disturbing objects e.g. pedestrians from the point cloud helps the modelling. By the limitation of the examined field, the used database can be reduced and post-processing requires less computer memory.
The modelling was created mostly in Cyclone and CloudWorks software.

2. ARCHAEOLOGICAL DOCUMENTATION FROM LASERSCANNING

During evaluating, the surroundings can be represented by more details, not only the main characteristics. Depending on the ground, triangulated surface models are easiest ways to create contour maps beside ground-plan and overviews. The goal of the survey in the ruin park was to complete the previous maps with more details and precisely, as well as documenting the actual condition of the monuments.

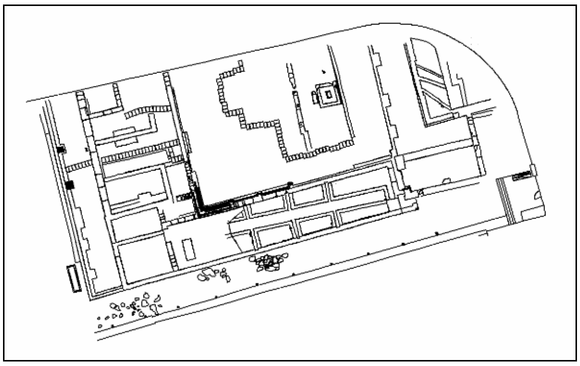

Figure 1: Ground-plan detail of the Ruin Park Budapest, Aquincum Museum

The scanning procedure lasted 2 working days and during this time 15 scan positions were used. The whole process of evaluation including registration and pre-processing took about 10 work days. The main characteristic of the survey was that the ruins are located in a small field, and there were many hidden parts. Brickwork drawings aren't needed, because the original wall remains are usually under the ground. Although the visible ruins are mostly reconstructed, both the upper and the bottom edges was drown. In the middle of Figure 1 there is a sanctuary with original remains. The crumbled parts are also evaluated.
The top of the original wall ruins were signed to distinguish from reconstruction.
The ground-plan – derived from laserscanning – is based on the above mentioned three-dimensional wireframe and gives information from the objects' spatial position.

Examining the upper and the bottom edge of the walls, the building structure can be concluded from the wall reclination,. The direction of street structure allows finding the continuation of the roman civil town.
Forming the layer structure during evaluation, different product can be achieved with more or less details. Expanding the simple wireframe model with crumbled parts, the actual condition mapping doesn't require much more time . Mapping overviews benefit from wide-range scanning. Due to the panoramic scans, the objects' environment was surveyed as a derivative. Occasionally the excavations are close to the museum or to each other. Wide range (2 m to 1000 m) can connect the scenes, and cover the surroundings of them. Otherwise farther from the scanner, the distance of two abreast laser beams growing according to the corresponding angle step width of the scanner. In horizontal case 100 m distance has about 14mm minimum horizontal scanning resolution.
Due to the discrete measurment, the objects aren't represented by their essential points, and this method reduces the accuracy of identification. In fact, the overview contains more topographic details while the required plotting scale enables this accuracy in the less important parts. Transforming to EOV, the museum and the outer part can be cross-checked.
The advantages of terrestrial laserscanning in archaeological fields are the high-detailed surveying and mapping on a large-scale, wide-range; the speed of the measurement and mostly follow-up watching 3 dimensional modelling.

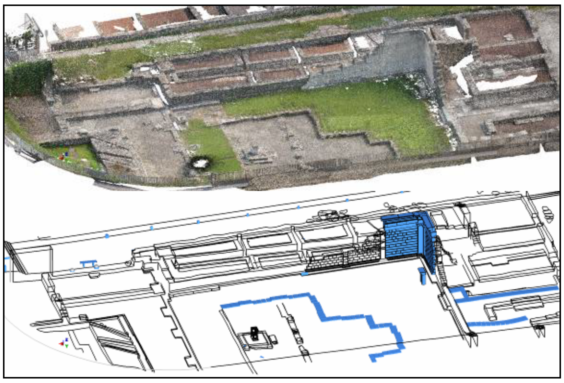

Figure 2: Pointcloud and wireframe model
Budapest, Aquincum Museum

The conditions during a surveying in reconstructed field mainly differ from a real excavation. On the coast of the Danube far from the museum, newly discovered ruins have been found. The excavation ditch was about 50 m long, 3 m wide and 1.5-3 m deep. The overview was created considering the previous experiments. Because of the lack of place, the minimum scanning range made the survey harder. In total, nine scan positions have been necessary to cover the ditch. The whole post-processing with brickwork drawing evaluation were created in 10 workdays. The wall ruins contain different types of irregular stones. As it can be seen on the screen, some bricks are bedded in mortar and it is hard to make distinction between this two things. Because of the multiple projections, the orthophotos don't contain enough colour information, and the boundaries of the bricks aren't contrasted enough. Hence the brickwork drawings were created by point cloud in Cyclone. With laserscanning, it is possible to determine the best adjusted vertical or horizontal plane to the surface of the walls.

Applying these plans as two dimensional reference planes, the detailed ground-plan and the brickwork drawings can be evaluated. This method is theoretically similar to the traditional survey, but the reference wall and the evaluation is more accurate. (Figure 7.and 8)
Roman wall ruins can stand on a wider socle. Socles are signed with stripped hatch in the bottom of the walls in Figure 3. Sometimes the edge of this base moulding is hard to recognize without architectural knowledge. In an excavation field or ditch walls are close to each other or to the ditch. These are not appreciable in every case. Hence, during the evaluating the model space was sliced into pieces. Cut planes and point cloud slices allow different views from the objects, and reduce computer usage. The near and far planes were evaluated with parallel slicing of the point cloud, in order to map the socles and other characteristics of the wall; both the nearest and the far wall contour were drawn.

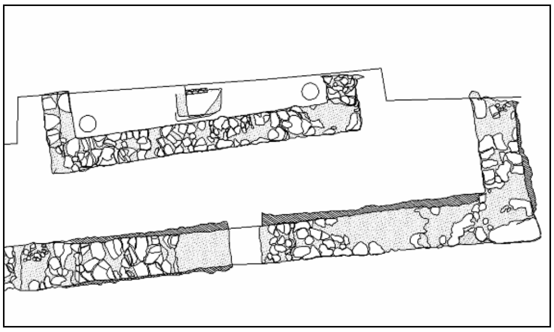

Figure 3: Ground-plan detail
Budapest, Danube coast, Pok Street

Usually orthophotos can be the base of the drawing, the wall surface has to be cleaned. Orthophoto and point-cloud based drawing are compared in Figure 4. Both of them have the same reference plane. As it can be seen, the drawing perfectly fits around the orthophoto. Only at few parts is not the colour information enough or leads to false conclusion. In this case 3D can help. Otherwise, orthophoto is faster and contains more information with less work.
The result strongly depends on the archaeological knowledge of the evaluating person.

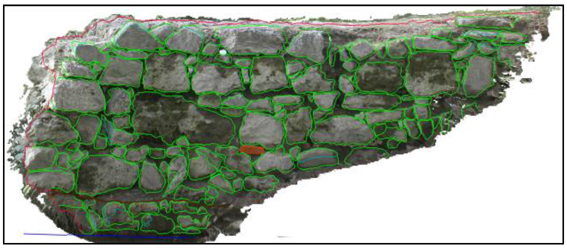

Figure 4:Comparison between orthophoto and brickwork drawing, Budapest, Bridge-head, Mozaik Street

By triangulating the point cloud, the 3D model becomes more realistic. On Figure 5 the triangulated mesh was textured with the images. This model is spectacular, but in general it is hard to use, requires technical knowledge, and high-speed computer. The computer usage mainly depends on the number of triangles. Before triangulation the point cloud was resampled to reduce the number of triangles and the computing time in RiscanPro. The resampling methods smooth the edges and the surfaces.

After excavating the ditch, it was filled up. These triangulated meshes remain the only way to examine the field as on scene. Subdivision helps to speed up the modelling. Besides reducing the number of triangles the accuracy of the tin can be preserved with keeping the curvatures.

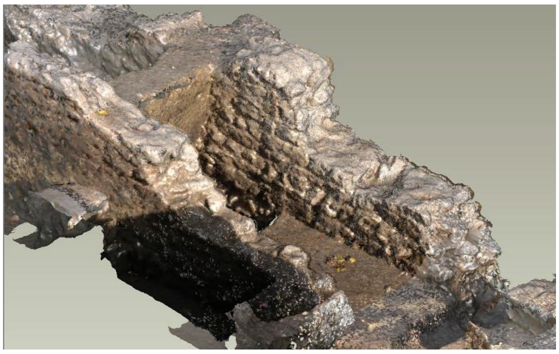

Figure 5: Triangulated textured mesh from excavated wall, Budapest, Danube coast, Pok Street

The disadvantages of these models are presented in the following sentences. The commonly used CAD softwares didn't or hardly manage the triangulated meshes. The coasts of processing softwares are too high and the free viewer applications can't be applied for analyzing. Of course the main problem is the I/O format of the meshes. Usually the point cloud import is solved, but in case of meshes, it is not so easy. The true-colour can lost with pushing a button and tin can collapse to triangles, etc… Fortunately, in Riscan Pro we could solve these problems, although to bring back the results aren't successful in every case.
In the end, the aim of the survey is to create archaeological reconstruction from the excavated area and helps the archaeologists' work. The simplest way to make it, is using the wireframe model of the walls in CAD software, and completes the missing or ruined parts. Firstly the wall sides were created with meshing from the evaluated wireframe. The result is similar to the surveyed objects but simplified to the main characteristic. Completing with missing parts was made with an archaeologist's co-operation. Figure 6. shows the completed mesh model. Different yellow colour shows ruined walls, the red surfaces are inner floors and grey is the outer floor. As you can see, the building structure is continuing on the top of the picture, but unfortunately these walls are under the bicycle-way. Hence this field
Other possibility for making reconstruction is chronoscope establishing. With this construction the ruins can be visible as it would be rebuilt. Placing this device on the scene - through a sighting slot - a computer projects a 2D picture from the same view. These kinds of devices are usually placed in ruin parks, around castle remains, etc.…
With laserscanning, the placement of this device is simplified. Scanning from the future place of the chronoscope, the scanner measure 3D the same colour view. From this measurement in Riscan Pro can be create a 2D view that can be the base of the chronoscope picture. From 3D measurements, the objects spatial positions are known. The reconstruction can be made by an architect with editing he 2D view of the scan.
can be surveying only with geophysics.

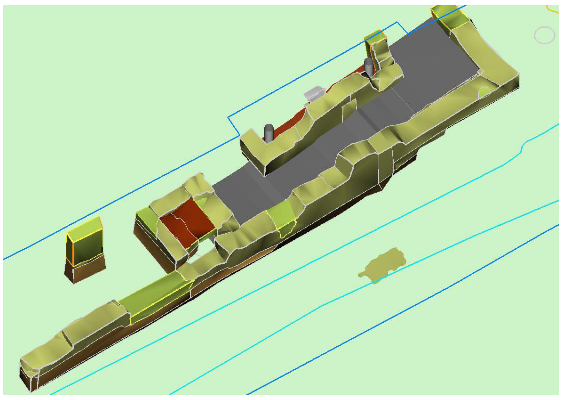

Figure 6: Reconstruction plan derived from 3D modelling, Budapest, Danube coast, Pok Street

3. COMPARISON

3.1 Comparing with traditional geodesy

Laserscanning was made beside traditional survey, thus the situation gave reason for making comparison between technologies. Firs, lets start with the advantages of laserscanning. Summing up the products contain more detail, which are more accurate in many cases. The scanner can measure wide-range, and last but not least allows the follow-up watching of the excavation and modelling in 3D. The dense discrete point sets with colour information permit 3D smooth surface creation.
During modelling, optional views and slices can improve the visibility and with extremely thin slices every cross sections can be made from the object. Hardly visible parts can be made visible – e.g. socles - more than on the screen, and from top view more characteristics are shown, and became for representation, than measuring countable points from the sides. The ground-plans can represent more break point of the wall and small slants. Comparing the brickwork drawings in Figure 7 and Figure 8, it can be seen many differences. The applied reference plane caused 4cm deviation in case of 16 m wall-length.
The brickworks plotting scale is 1:40, so in this case the plotted difference is 1mm. Both brickwork drawing contains the required details and needed same time and fewer people. In case of laserscanning, the drawings were evaluated in office, with a precise reference plane definition from orthogonal view. Contrary, on scene the plane was defined practically with the help of nails, and the bricks were mapped within square grid. In traditional case, the survey had to be inked over after the survey. In Figure 7, the details are cleared-out and not last the product is in CAD software.
The evaluation in the locked reference plane from orthogonal view is more accurate and time-saving.
In the office, the cross-section making is easier, more accurate and can be made in every case, when the object is not hidden. The final result must be more accurate, because of the high-resolution scanning process that records everything, despite of surveyor accessories. However, our archaeological knowledge was scanty before these projects, after short time the evaluation became more efficient.
After the advantages of laserscanning, I have to mention the disadvantages also. Firs of all, the scanned pointcloud requires technical knowledge, expensive softwares,

computer memory and disk space. Though the pointcloud is spectacular, only the processed products or colour 2D pointcloud views can be use in every day. In spite of other accessories, the laserscanner can't aim the objects, just measure discrete points on the visible surface as near as the minimum step angle allows considering the distance from scanner. Otherwise in case of vegetation, the laser-beam reflects from the visible surface, measuring mainly the top of the vegetation and the ground.

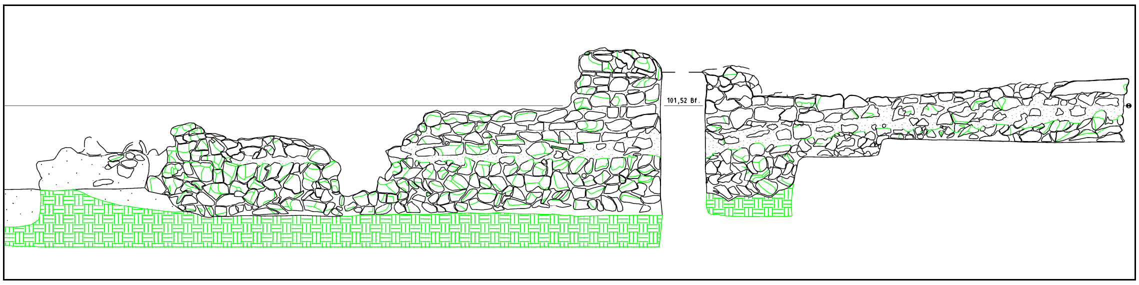

Figure 7: The evaluated brickwork drawing prepared by laserscanning made in office

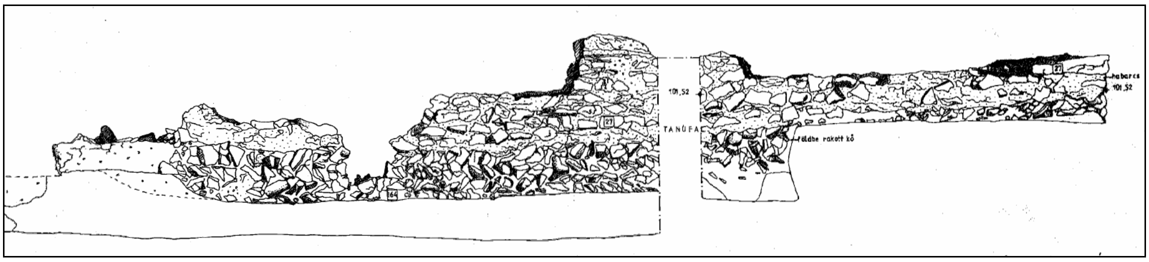

Figure 8: The traditional mapping product. (paper based, made in the survey field)

3.2 Comparing with Photogrammetry

As we could see formerly, orthophoto creation speeds up the evaluation, and can be the spectacular metric part of the documentation, with obvious information. In that cases when the accuracy of laserscanning is not satisfactory for the final result, applying orthophoto can represent more detail than the scanner can measure. The scanned data is not continuous, although contains colour information. Creating triangulated meshes and supplying them with texture from images can improve the accuracy. Usually people have to decide that which is more important, 3 dimensional large, hardly usable files or a metric image.
The true orthophoto combine the benefits of photogrammetry and laserscanning using the surface model from scanning and photo images with known position. Getting to business, the true orthophotos are provided with depth information, which based on the scanned data. The external orientation elements are precisely known and corrected with the camera mounting process if it is necessary. This method results the best accuracy. In photogrammetry, the orthophoto base on characteristic points, simplified surface models, and eliminate the distortion of pictures with perspective transformation, or with other transformations. With laserscanning the surface is known or the difference is smaller than it could cause considerable distortion.
In most cases this kind of documentation can be made easier than drawings. The photos are wide-spread in everyday usage, contrary other products, don't requires any other technical background. Otherwise for example in cases of roman tessellated pavements, the drawing doesn't describe the colours and making a drawing piece by piece is certainly not the more efficient way to document them. Figure 9. shows a tessellated pavement in the Aquincum Museum. The picture was taken from the side, because the room was low-pitched, dark and tiny.
Other applications can be the documentation of stratum, in the excavation ditch. With orthophotos, the stratification are known and don't need to make ambiguous colour definitions from the different type of stratum.

Figure 9: Orthophoto from tessellated pavement, Budapest, Aquincum Museum

4. CONCLUSION – FUTURE PLANS

In the near future the 3 dimensional models can be the geometrical base of databases. As it was mentioned above, laserscanning is rapidly developing field of science that can attend the other sciences. The quality of the products improves day by day due to the software developing companies.
As a result we aimed a product, that is not only satisfactory for documentation, but provide for more information. Otherwise we were standing for time-saving, efficiency and last but not least the usability. Comparing different methods, laserscanning proved to be more efficient. Our experiments intended mainly for let out the possibilities for archaeological analysing and attend this

user group with usable products, without bothering them without technical knowledge.
In cases of long and tiring surveys like brickwork drawings, the work on the excavation field can be reduced. It was typical of our projects that the excavation causes stoppages in other work, e.g. public service construction. Roman culture differs from other fields of cultural heritage. The most characteristic findings are ruined walls close to each other, but at times there are roman coach graves or outcropped ship models. This searching project may contain more challenge in the future. These findings are pushing the envelopment of the terrestrial laserscanning and close-range scanning.

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