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Maja GRGURIĆ & Zlatan NOVAK

USING 3D LASER SCANNERS ON ARCHAEOLOGICAL SITES

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In order to fully understand and interpret an archaeological site, it must be recorded and documented in detail. There are two types of archaeological documentation – the, so-called, direct surveys which usually include a pencil, piece of paper and a tape measure, and the second type which includes indirect techniques like total stations, 3D optical instruments, drones or a simple camera. More time to collect data is required when applying the first approach, meaning that more people are a prerequisite for speeding up the process, which leads to "not fully precise" and subjective data acquisition. On the other hand, indirect techniques, like 3D laser scanning discussed in this paper, are less time consuming and provide more accurate documentation. 3D scanning may also improve object accessibility, can aid expert understanding, and enhance relations with the general public.

Key words: 3D laser scanning, archaeology, archaeological documentation, conservation, cultural heritage

Introduction

Simple definitions of 3D scanners state that it is any device which collects 3D coordinates of a given region of an object's surface automatically and in a systematic pattern at a high rate (hundreds or thousands of points per second up to million points per second), obtaining results (i.e. 3D coordinates) in near real time. 3D scanners are used as stationary equipment placed on fixed positions, as mobile systems on tripods or similar stands for close and mid-range applications, or as airborne systems for topographic applications. The term 'laser scanner' is generally applied to a range of instruments which operate on different principles, in different environments and with different levels of precision and result accuracy. The recording of the position, dimensions and/or shape is a necessary part of almost every project related to the conservation of cultural heritage, and it is an important element of the documentation and analysis process (Böhler *et al.* 2002: 1). The use of a 3D laser scanner depends on the expected and required results. For example, a conservator might want to know how quickly a feature changes, while an archaeologist might be interested in understanding how one feature in the landscape relates to another, an engineer might simply want to know the size of a structure and where existing services are located. Additionally, 3D laser technology contributes to the production of three-dimensional models, animations and illustrations for presentation in visitor centers and museums, as well as on the internet and in the media (enhancing accessibility/engagement and improving understanding) (Jones 2011: 3).

Why a 3D laser scanner?

The traditional hand measuring documenting method is the cheapest way of collecting data required at an archaeological site. Collecting this data *in situ* at any moment, as well as the ability to measure hard to reach places, makes hand measuring a simple and practical tool. Apart from that, it has become an unpopular method due to it being time consuming, inaccurate, subjective, and having no coordinate reference (Gonizzi *et al.* 2012: 1). Scaled drawings limit the extent to which very precise information can be recorded, displayed, and retrieved. The geometric recording of monuments on a large scale, i.e. larger than 1:100, presents several difficulties and peculiarities which call for special attention by the user (Haddad 2011: 110).

Everyone's favorite - the total station, provides quick automated determinations of prominent single points, sections and profiles, as well as outlines of difficult-to-measure objects with curved surfaces. It can also produce 3D wire frame models with high absolute point accuracy (Haddad 2011: 110). It is a data collecting method which provides accurate results and is significantly less time consuming than drawing by hand. While the data are being collected during the excavations, either by using a prism or a laser beam, the drawing part has been transferred to a comfortable office. On the other hand, subjectivity factor, complexity of the total station and thereby connected drawing programs, and a needed skill to operate the sophisticated drawing software still tend to drive off a significant number of users.

Today, 3D laser scanners are the most advanced available technology used to measure and document objects. In short, 3D laser scanners are part of a non-destructive and non-contact technology which enables for 3D measurements of a large amount of points in a short period of time. By directing a laser beam to the horizontal and vertical plane, and rotating the instrument around its axis, terrestrial laser scanners (TLS) measure a large number of points in a 3D coordinate system (Golek *et al.* 2012: 55). The result is a measured surface of an object, called a „point cloud", which contains millions of XYZ points. Depending on the distance from the object being measured and the technical specifications of the instrument, the measured points can even be millimeters apart. Besides the spatial (relative or absolute) coordinates, a point cloud can also contain the color of the reflected surface (RGB) (Miler *et al.* 2007: 35). Considering the need for ultimate precision, along with the speed of acquiring data, this kind of new technology appears to be the right solution to many problems, and it also introduces a new kind of interdisciplinary collaboration (between archaeologists and mostly geodesists).

3D laser scanning vs. photogrammetry

As mentioned before, 3D laser scanning is still the most advanced and accurate method of fast 3D spatial data acquisition. Terrestrial based LIDAR systems collect up to one million points per second and each point is determined immediately like the single point measured with the total station. LIDAR combined with inertial systems can be used on moving platforms such as a person mounted backpack, road vehicle, marine vessel or an aircraft, allowing detailed point clouds of larger areas. If we compare it with today's alternative methods such as photogrammetry, we are talking about completely different technology. When laser scanner defines each point accurately by firing laser pulses that reflect from the object surface, photogrammetry has a different procedure and data processing methods to extract each 3D point. In other words, in photogrammetry a point is not a directly measured feature. Each point has to be calculated afterwards using algorithms trying to find and match same details from many images shot with a camera in order to extract geometry. However, the geometry cannot be measurable if we do not use total station, or a 3D laser scanner to have accurate control points. More control points we have, more accurate the photogrammetric model will be. On the other hand photogrammetry provides more photo-realistic 3D models, depending on the quality of the camera. Accuracy depends on many aspects such as camera setup, resolution, complexity of an object, etc. Our experience showed the best results when combining the two technologies. Some details can be better presented when using photogrammetry, but we get the best results if we have precise geometry of the same detail acquired with the 3D laser scanner as the basis for the photogrammetric 3D model. For example, 3D laser scanner can acquire millions of points of a high medieval wall, but point spacing on the top of the wall can reduce up to 1-3 cm, and we can also get some shadows due to the scanner position. With the use of an UAV (unmanned aerial vehicle) such as multi-rotor flying system with camera, we can acquire detailed photographs of the top (Fig. 1). Overlapping precise geometry from the 3D laser scanning point cloud and the photogrammetric 3D model we can achieve high accuracy of the photogrammetric 3D model, and collect the details that could not be acquired by a 3D laser scanner.

it helps uncover previously unnoticed archaeologically significant features such as tool marks on artefacts, and it can be used to study landscape covered in vegetation or woodland, thus providing a spatial analysis which could not be made without three-dimensional data such as line of sight or elevation exaggeration (Jones 2011: 5). In archaeological documentation, objects range from small artefacts and sculptures to large areas of land. The larger the archaeological site, the quicker data needs to be collected. Since there is usually only a limited amount of time and money available, new techniques are highly welcomed. Systematic excavations of larger

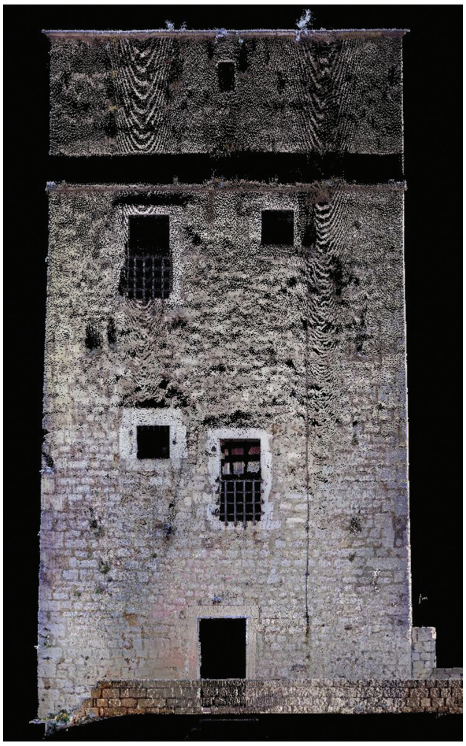

Fig_1a

Fig_1b

Figure 1. Comparison of a point cloud created by 3D scanner and a photogrammetric 3D model (by: Vektra d.o.o.)

buildings and architectural complexes require ultimate precision in spatial data collecting (Fig. 2).

If the trenches are being covered up after every season, or if the research includes an urgent construction intervention or a reconstruction, having a 3D model of the site only a few days after the excavations can be more than helpful. Organic materials like wood are prone to rapid deterioration, so having a 3D model of wooden features *in situ* is almost a privilege. Rescue archaeology usually entails the complete loss of all archaeological finds

Archaeological excavations and 3D laser scanning

When a feature, structure or site might be lost or changed forever, e.g. through archaeological excavations, the most important goal is to obtain detailed documentation. 3D laser scanning is a form of spatial data documentation that aids with the interpretation of archaeological features and their relationship across a landscape, thus contributing to our understanding of the development of a certain site and its significance for the area. Furthermore,

Figure 2. Using a 3D laser scanner on an archaeological site (by: Vektra d.o.o.)

which cannot be documented or transported to a museum. Typically, archaeologists are met with unrealistic demands, including recording and documentation, due to the pressure of construction contract deadlines.

The following examples are going to show exactly how 3D laser technology can bring archaeology to a whole new level (Map 1). Instruments used for 3D spatial data acquisition in presented cases are a terrestrial laser scanner Z+F Imager 5010C and a handheld scanner ZScanner 800.

Map 1 List of sites mentioned in text - 1. Varaždinske Toplice, 2. Koprivnica, 3. Zadar, 4. Pula, 5. Ježdovec (by: Vektra d.o.o.)

Varaždinske Toplice - lost in the Roman pool

Varaždinske Toplice is today's name of the Roman settlement *Aquae Iasae*, which was located at the same place from the 1st to the 4th century AD. The location is best known for its thermal spring which has been used since the time of the Roman settlement. Intensive systematic excavations have been going on since 1953 (Gorenc *et al*. 1980). Dorica Nemeth-Ehrlich and Dora Kušan-Špalj from the Archaeological Museum in Zagreb, who have been running the excavations in recent years, have introduced the 3D laser scanning technology at the site. The most complex part of the site is the Roman spring-fed pool. Every year, before any type of excavation can be undertaken, the pool has to be emptied, and once the research ends, the water has to be brought back in. Apart from being a challenging architectural puzzle with numerous finds, the pool is full of sticky mud which makes the excavations even harder. Considering the complexity of the stratification, the inevitable destruction of upper levels, the limited time available, as well as hard working conditions, a 3D laser scanner presented itself as the perfect solution for all of the listed problems. 3D laser scanning was conducted every few days, as the next layer of architectural elements appeared. Depending on the complexity of the scanned objects, the whole process would take from one to a few hours of work. A complete 3D model of architectural remains, some of which have now been lost forever, was made in a matter of days (Fig. 3).

At one point of the excavation, wooden pillars emerged from the muddy sediment. They were scanned right away, *in situ*, so they could be taken out instantaneously. Apart from the terrestrial laser scanner, a smaller handheld 3D scanner was also used to scan various stone sculptures and stone inscriptions on *spolia*

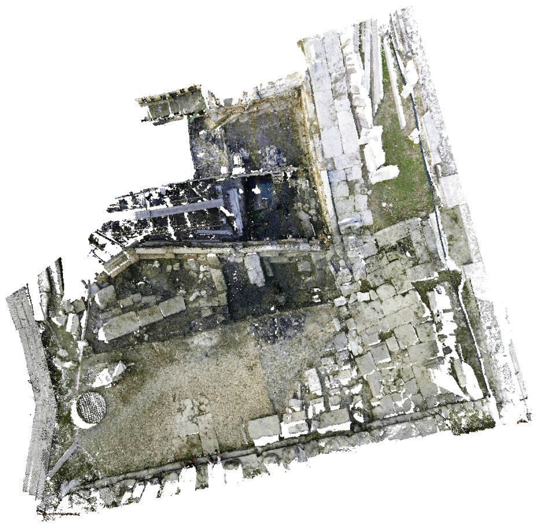

Figure 3. 3D model of the Roman pool and the surrounding area in Varaždinske Toplice, Archaeological Museum in Zagreb (by: Vektra d.o.o.)

which could not be removed from the pool (Fig. 4), resulting in more detailed and precise information.

Figure 4. 3D laser scanning of a stone inscription in situ in Varaždinske Toplice, Archaeological Museum in Zagreb (by: Vektra d.o.o.)

In 2013, fragments of statues of Apollo and Diana were uncovered in the pool, and they became the highlight of the season. As soon as they were taken out, the fragments were scanned at the temporary depot. After only a few days of data processing, Apollo was back on his feet, at least in a virtual environment. The complexity of the site made it a perfect training ground for 3D laser scanner data acquisition. By applying this technology, the time required for complete architectural documentation was reduced by months, if not years.

Rescuing a bridge, a wall and a ship

In 2013 and 2014, a part of the medieval fortification in Koprivnica was excavated in order to obtain more information on the 16th century fortress as part of a revitalization project. The excavations were run by Robert Čimin from the Koprivnica Town Museum. An area of around 1000 m^2 gave new information about the way the fortifications were built (Čimin 2014: 9). Since the archaeological trench had to be filled back in right after the excavations, and with only a short amount of time offered, 3D laser scanning was the only available solution. After the archeological excavations ended, the site was completely documented, perfectly preserving a large amount of wooden pillars from the rampart construction, the remains of a bulwark, and a wooden bridge in the form of a 3D model (Fig. 5).

The whole scanning process only took a day of work at the site. The exact distribution, direction and width of bridge pillars made further plans for the bridge reconstruction easier. Through this process, the Koprivnica fortress revitalization is a step closer to its final stages.

A similar case occurred in Zadar in 2014, where a deserted backyard in the town center had to be reopened for the public. The backyard is surrounded by old city walls (Suić 1958: 13; Suić 1976: 14; Fadić *et al.* 2011: 325), so archaeological excavations had to be undertaken, and a similar approach as the one used at Varaždinske Toplice was used. The excavations were run by a private company Vektra d.o.o. and the Archaeological museum in Zadar. Every time a layer of architectural construction had to be removed, 3D laser scanning technology was applied (Fig. 6).

It was impossible to make profile or section drawings at the site, and there were no ground plans to

Figure 5. 3D model of the excavated area in Koprivnica with wooden pillars, Koprivnica Town Museum (by: Vektra d.o.o.)

Figure 6. A detail of a 3D model of an early medieval wall in Zadar, Vektra d.o.o. (by: Vektra d.o.o.)

help document and keep up with the situation at the site. However, everything was visible from each 3D model made during the excavations. In the end, all the measurements and drawings were produced in the office using exclusively 3D models of the site (Fig. 7).

In 2013, during a street reconstruction in Pula, a perfectly preserved Roman wooden ship was discovered. The excavations were run by Ida Kocani Uhač from the Archaeological Museum of Istria in Pula. Although the ship is 2000 years old, the mud kept various organic finds almost intact. Wooden planks and pegs, as well as ropes, were perfectly preserved, as was a part of the construction. Since the ship was almost 6 meters beneath the walking surface, taking it out in one piece became a real challenge. Even after extraction, the ship would need to be treated with various chemicals for years before it could be fully conserved and ready to be studied. Again, the 3D laser scanner proved to be the perfect solution. The ship was scanned *in situ*, making it ready for complete study after only a few days (Fig. 8).

Piecing together the past

One of the most exciting challenges was the above mentioned Apollo statue from the Roman settlement in today's Varaždinske Toplice. The statue was broken into nine pieces (some parts are still missing) which were found inside the thermal pool. The moment they were taken out and cleaned, a hand-held 3D laser scanner was used to document individual pieces of the statue (Fig. 9).

This kind of method provides easier access to the subject, and the results are in a much higher resolution than they would be if obtained by a terrestrial

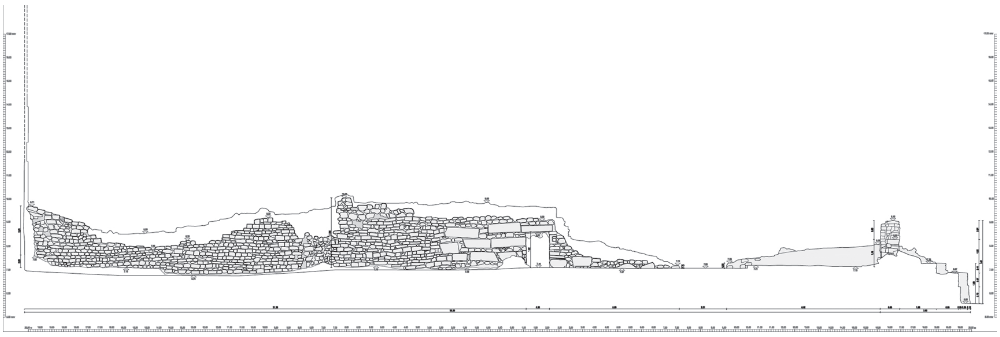

Figure 7. An example of an Autocad drawing based on a 3D model (by: Vektra d.o.o.)

Figure 8. The 3D model of the ancient ship found in Pula, Archaeological Museum of Istria (by: Vektra d.o.o.)

Figure 9. 3D laser scanning of elements of the Apollo statue from Varaždinske Toplice, Archaeological Museum in Zagreb (by: Vektra d.o.o.)

3D scanner. The entire process took 2 days, resulting in a 3D model of each piece, enabling us to put the pieces back together in a virtual environment (Fig. 10).

The result was a 3D model of the entire statue of Apollo which could be viewed and studied without having to wait for its restoration. Not only the statue of Apollo, but a statue of Minerva, Diana and various architectural stone elements were also scanned and put back together where possible, providing researchers easy access without having to operate with heavy objects. The same approach can be also used on other finds, made of of wood, objects like pottery, etc. We would like to highlight the fact that there is no impact of any kind on the object's physical integrity.

3D scanning of smaller objects discussed here proved to be very helpful for deciphering damaged inscriptions on stone objects. A nice example is an ancient milestone from Ježdovec near Zagreb. The milestone is more than 2.14 m tall, and has a heavily damaged inscription. It is currently located in the backyard of the Zagreb City Museum, meaning it is exposed to

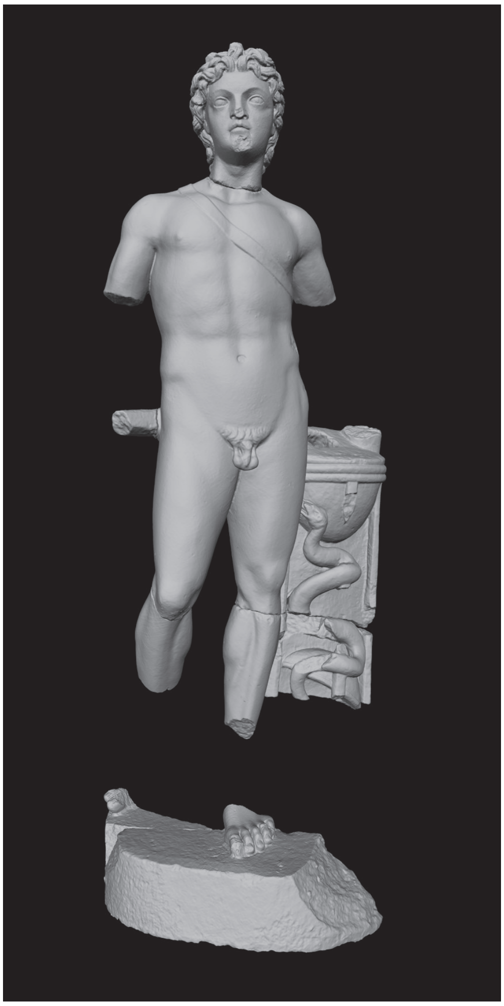

Figure 10. Elements of the Apollo statue pieced together in a virtual environment (by: Vektra d.o.o.)

all kinds of weather conditions and only a limited light source, which makes the inscription hard to read. Seeing as the monument is too large to move, a handheld 3D scanner was applied once again. The result was a monochrome 3D model that could be easily viewed, and, more importantly, virtual lighting could be added and positioned in selected angles during viewing so that the inscription could finally be visible and readable (Fig. 11).

Figure 11. The ancient milestone from Ježdovec with inscription – 3D model, Zagreb City Museum (by: Vektra d.o.o.)

Conclusion

Laser scanning, either conducted from the air or from the ground, allows for a large quantity of three-dimensional measurements to be collected quickly. Having a 3D laser scanner on an archaeological site makes the non-reversible techniques "less painful". Not only are objects virtually preserved, but they can also be brought into the virtual workroom in the form of a 3D model. In this way, all the drawing documentation is taken to the office. Measures, sections and heights can be taken at any time, without the need of going back to the site. 3D models, or even replicas of various objects, are now available for research and can be displayed to the general public. This process even enables the creation of replicas used for study, which can be made on any scale, as well from almost any material. The attention of the public is drawn by 3D models of various archaeological sites and objects, making museums and heritage sites more popular.

Bibliography

Čimin 2014 — R. Čimin, "Prilagodbe u arhitekturi podravskih utvrđenja pojavom osmanlijske opasnosti", *Podravina* 13/26, Koprivnica, 2014, 5 – 19.

Böhler & Marbs 2002 — W. Böhler & A. Marbs, "3D Scanning Instruments", *Proceedings of CIPA WG6 Scanning for Cultural Heritage Recording*, Corfu, 2002.

Fadić & Štefanac 2011 — I. Fadić & B. Štefanac, Geneza grada na Trgu Petra Zoranića, *Histria Antiqua* 20, Pula, 2011, 325 – 331.

Golek, Dobrinić & Kordić 2012 — D. Golek, D. Dobrinić & B. Kordić, „Usporedba terestričkih laserskih skenera, *Ekscentar* 15, Zagreb, 2012, 55 – 61.

Gonizzi Barsanti, Remondino & Visintini 2012 — S. Gonizzi Barsanti, F. Remondino, D. Visintini, "Photogrammetry and Laser Scanning for archaeological site 3D modeling – Some critical issues", V. Roberto, L. Fozzati (*eds.*) *Proceeding of the 2nd Workshop on 'The New Technologies for Aquileia'*, 2012, 1 – 10.

Gorenc & Vikić 1980. — M. Gorenc & B. Vikić, *Varaždinske Toplice – Aquae Iasae u antičko doba*, Varaždinske Toplice, 1980.

Haddad 2011 — N. Haddad, „From ground surveying to 3D laser scanner: A review of techniques used for spatial documentation of historic sites", *Journal of King Saud University - Engineering Sciences* 23/2, Jordan, 2011, 109 – 118.

Miler, Đapo, Kordić & Medved 2007 — M. Miler, A. Đapo, B. Kordić & I. Medved, „Terestrički laserski skeneri", *Ekscentar* 10, Zagreb, 2007, 35 – 38.

Suić 1958 — M. Suić, "Novija arheološko-topografska istraživanja antičkog Jadera", *ZborIhnZd*, knjiga II, Zadar, 1958, 13 – 49.

Suić 1976 — M. Suić, "Obrambeni sustav i prospekt antičkog Zadra s kopnene strane", *RadFfZd*, Zadar, 1976, 14 – 15.

https://historicengland.org.uk/images-books/publications/3d-laser-scanning-heritage2/ (accessed: 10 Sep 2015)