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The application of different 3D-scan-systems and photogrammetry at an excavation — A Neolithic dolmen from Switzerland

Inga Siebke[a], Lorenzo Campana[b,c], Marianne Ramstein[d], Anja Furtwängler[e], Albert Hafner[f,g], Sandra Lösch[a,*]

[a] Department of Physical Anthropology, Institute of Forensic Medicine, University of Bern, Switzerland
[b] Department of Forensic Medicine and Imaging, Institute of Forensic Medicine, University of Bern, Switzerland
[c] University Centre of Legal Medicine Lausanne-Geneva, University Hospital Lausanne, Switzerland
[d] Archaeological Service of the Canton of Bern, Switzerland
[e] Institute for Archaeological Sciences, Archaeo- and Palaeogenetics, University of Tübingen, Germany
[f] Department of Prehistory, Institute of Archaeological Sciences, University of Bern, Switzerland
[g] Oeschger Center for Climate Change Research, University of Bern, Switzerland

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ABSTRACT

The discovery of a Neolithic dolmen in Switzerland with inhumations, dating between 3500 and 3000 BCE, was an exceptional finding. To provide best conditions for subsequent studies on the archaeological remains our interdisciplinary team decided to apply 3D documentation. Depending on different factors, two scanning systems with four scanners and photogrammetry were applied and the obtained data was combined. Detailed excavation plans and simultaneously a reduction of excavation time without loss of information were the result. A virtual animation of the dolmen in its reconstructed ancient appearance combined with the context of the grave goods was created. The 3D documentation provided initial data for anthropological and paleogenetic analyses. The individuals buried in the dolmen might provide novel information to the Neolithic research of central Europe. Additionally, with the help of the 3D data, the dolmen was rebuilt to make this archaeological heritage accessible to the public.

1. Introduction

1.1. Archaeological background

For the Neolithic period, settlement and pile dwelling archaeology are well known and have a long research history (Palafittes, 2015; Schlichtherle and Hafner, 2013; Hafner et al., 2014; Stöckli, 2016). Approximately 60% of all recognized pile dwelling sites in the Alpine area are located within lake regions of nowadays Switzerland, including over 40 UNESCO World Heritage sites (Palafittes, 2015). This however is not surprising, as the preservation of wooden constructions is exceptional due to the environmental conditions. In contrast, burials have been rare (Fig. 1) and few anthropological or biochemical analyses were performed on human remains (Stöckli et al., 1995; Bleuer et al., 2012). The discovery of an undisturbed Neolithic dolmen in Oberbipp (Fig. 1, no. 1) was a surprising and exceptional finding in central Europe. Most Neolithic burial sites were discovered in Switzerland in the 19th and early 20th century and most information has been lost due to former excavation methods.

An exception has been the collective grave of Spreitenbach (Fig. 1, no. 10), which dates around 2500 BCE (Doppler, 2012), and two dolmen within the Neolithic and Bronze Age necropolis of Sion (Fig. 1, no. 21) with an approximated age of 3000–2600 BCE (Bocksberger, 1976; Favre, 2011). First radiocarbon dates of the skeletal remains of the Oberbipp dolmen indicate an age between 3500 and 3000 BCE, this makes it the oldest dolmen in Switzerland so far (Ramstein et al., 2014, 2013; Ramstein and Lösch, 2014). It is assumed that the dolmen was exposed at least until the 13th century, as Bronze Age, Roman, and Medieval deposits were located in direct external relation. In the strata below the dolmen construction, Mesolithic silex artefacts were found and radiocarbon dates indicate first human activity around the 10th/9th millennium BCE at the site.

The dolmen of Oberbipp had the approximate dimensions of 2.5 × 4.5 m and a total height of 1.5 m. The grave chamber consisted of four glacial erratic blocks carrying the granite capstone. Two additional blocks marked the entrance. The interior measures are about 2 m^2 with an original height of approximately 0.8 m. The floor was lined with limestone slabs and a door silt of tuff marked the entrance (Fig. 2). The

* Correspondence to: Department of Physical Anthropology, Institute of Forensic Medicine, Bern University, Sulgenauweg 40, 3007 Bern, Switzerland.
E-mail address: Sandra.Loesch@irm.unibe.ch (S. Lösch).

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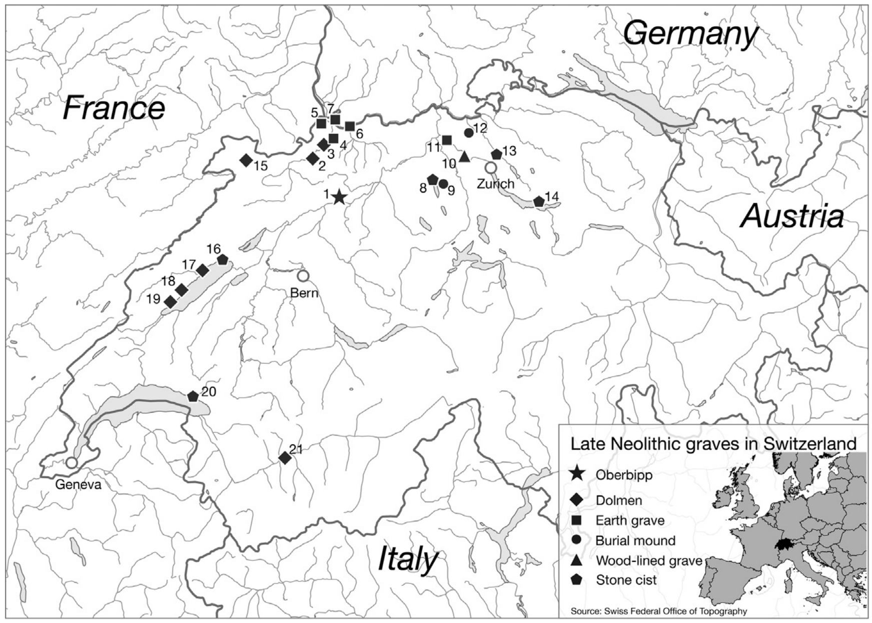

Fig. 1. Distribution and different types of late Neolithic graves in Switzerland: 1. Oberbipp; 2. Laufen; 3. Aesch; 4. Arlesheim; 5. Allschwil; 6. Kaiseraugst; 7. Riehen; 8. Seengen; 9. Sarmenstorf; 10. Spreitenbach; 11. Baden; 12. Schöfflisdorf; 13. Opfikon; 14. Rapperswil; 15. Courgenay; 16. Saint-Blaise; 17. Colombier; 18. Fresens; 19. Onnens; 20. Corseaux-sur-Vevey; 21. Sion.

original entrance was probably enclosed by a slate block. A dredge, however, removed this before the archaeologists were informed. The upper soil layers revealed scattered skeletal remains and indicated disturbances. One of the disturbances is observable in the whole profile of the interior. The lower soil layers were filled with human remains, some of them partially in anatomical association. Repositioning of skeletal elements during the use of the dolmen but also in later times due to human and animal activity as well as environmental influences are most likely, indicated by the high number of scattered remains.

The individuals were mainly found in extended supine position with the skulls predominantly in the south towards the entrance of the dolmen. Based on the number of skulls observed on the excavation, a minimal number of 30 individuals were postulated. The anthropological *in situ* documentation also indicates the existence of all age classes and both sexes. The typology of the grave goods is comparable to findings at contemporary stilt house settlements on lakeshores of the Horgen phase (Swiss late Neolithic).

The human remains from the dolmen at Oberbipp provide a unique opportunity to study this population with regard to demographics, diet, migration patterns, kinship, and diseases as the preservation and documentation is given (Siebke et al., 2017; Furtwängler et al., 2018). In difference to most other megalithic burial sites in Switzerland dolmen the contained exceptional well preserved skeletal remains and was field-documented with 3D scanning technologies. Additionally, guidelines for the recovery of skeletal samples for further paleogenetic analyses was followed (Burger and Bollongino, 2010).

1.2. Application of 3D documentation

An excavation has the purpose to uncover information about past populations based on preserved artefacts and structures. The major issue archaeologists face is the fact that excavations are destructive. During an excavation, artefacts become isolated from their context and are preserved independently while structures usually are destroyed. This makes the choice of *in situ* documentation the most essential decision at the beginning of each excavation (De Reu et al., 2014, 2013). Conventional documentation methods such as true to scale drawing, photographs, and individual altimetry provide a 2D image of individual layers and profiles of an actual 3D structure (De Reu et al., 2013). It is a general issue in archaeological science when former excavations get reviewed to test new hypotheses, that information is lost due to poor documentation or that particular elements had not been recorded at all (Subirà et al., 2016). With the application of 3D documentation techniques on archaeological excavations, this chal-

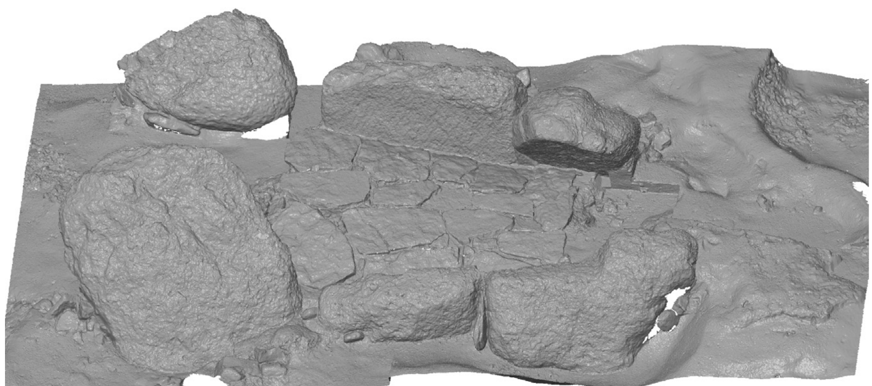

Fig. 2. The excavated dolmen. Visible are the two blocks marking the entrance on the left (south), the four blocks which carried the capstone and the limestone which lined the floor of the dolmen.

lenge might be limited or overcome. The increasing number of publications about 3D documentation and reconstruction over the last years indicate that those methods are frequently used in cultural heritage (Bruno et al., 2010; Ducke et al., 2011; Gilboa et al., 2013; Güth, 2012; Kuzminsky and Gardiner, 2012; McPherron et al., 2009; Clarkson and Hiscock, 2011; Corns and Shaw, 2009; Dellepiane et al., 2013; Grosman et al., 2008; Karasik and Smilansky, 2008; McCoy and Ladefoged, 2009; Niven et al., 2009; Rua and Alvito, 2011; De Reu et al., 2014; Neiß et al., 2014; Koutsoudis et al., 2014; Galeazzi, 2016; Grün et al., 2004). During archaeological excavations, total stations to measure local coordinates of single points (Kvamme et al., 2006; Rua and Alvito, 2011) and photogrammetry (Apollonio et al., 2011; Corns and Shaw, 2009; Dellepiane et al., 2013; Ducke et al., 2011; Kvamme et al., 2006; Rua and Alvito, 2011; De Reu et al., 2014) are mostly applied. Recently recorded in the literature is the application of 3D scanning and virtual reality of either individual archaeological objects (Bruno et al., 2010; Dias et al., 2008; Neiß et al., 2014; Koutsoudis et al., 2014; Larsson et al., 2015) or as a substitute when traditional documentation methods are difficult to apply (Lai et al., 2015; Núñez et al., 2013; Galeazzi, 2016; Westoby et al., 2012; Hu et al., 2016).

There are two different available 3D scanning systems, according to literature: one is a laser scanner which records the surface via a laser pulse (Bruno et al., 2010; Clarkson and Hiscock, 2011; Corns and Shaw, 2009; Kuzminsky and Gardiner, 2012; McCoy and Ladefoged, 2009; Robson Brown et al., 2001; Dias et al., 2008); the other is a structured light topometry which records the surface via reflection of a light pattern, while the associated software calculates 3D coordinates for each pixel of the image based on the triangulation principle (Gilboa et al., 2013; Grosman et al., 2008; Güth, 2012; Karasik and Smilansky, 2008; McPherron et al., 2009; Niven et al., 2009; Pastoors and Weniger, 2011; Guidi, 2014).

Photogrammetry, such as Structure-from-Motion, which are often applied on excavations and heritage documentation nowadays (Böhler and Marbs, 2004; Pierdicca et al., 2016), as well as software, which is able to process "normal" photographs for 3D reconstruction (Grün et al., 2004), and laser scanning provide several advantages, when dealing with highly detailed sites such as collective or mass burials with commingled remains (Böhler and Marbs, 2004; Baier and Rando, 2016). The main factor why 3D documentation should be used in such a context is the fact that within a relatively short time a whole layer of a grave can be documented including every visible detail (Baier and Rando, 2016; Katz and Tokovinine, 2017). This reduces the required time in comparison to true to scale drawing and preserves original information of object positions (e.g. bones) highly accurate. In particular, fragmented remains are documented within the context, which facilitates subsequent examination (Baier and Rando, 2016; Katz and Tokovinine, 2017). An additional advantage is the fact that anatomical knowledge is not required for documentation. Conventional methods such as drawings are not just time consuming themselves; drawings also increases the time in which objects are exposed to atmosphere, become physically altered, contaminated, or can be accidentally repositioned. The latter might not be a major issue when dealing with (partly) articulated human remains; however, detailed and exact plans of each layer increase the chances to reassemble commingled remains later on.

From 3D documented data, it is possible to obtain scaled plans, just after processing, that can also be reprinted instantly, each one with the same quality. As Katz and Tokovinine (2017) discuss, in contrast to conventional archaeological methods, it is possible to scroll through the detailed 3D model (Animation 1) and its' different phases as well as study scaled isolated areas at will. Additionally, by means of 3D documentation, measurements can easily be taken after the recovery of items. This is particularly useful in cases where objects, e.g. bones, become damaged during recovery or cleaning as well as for reconstructing the burial sequences of multiple burials and mass graves. Whatsoever, it has to be remembered, that preparing 3D data for subsequent studies is still a time consuming process, which requires adequate infrastructure (Hermon et al., 2017) and could be overvalued in some cases where conventional documentation methods already provide the necessary information. From the cultural heritage aspect and for future evaluations of the archaeological site 3D documentation remains the most effective way of generating true to scale data, given that data is accessibly stored (Grün et al., 2004; Hermon et al., 2017).

Finally, with 3D documented data it is possible to create digital reconstructions (Güth, 2012) and to 3D print replicates of archaeological objects. Consequently, cultural heritage becomes more accessible for the public, either in terms of a monument itself or in terms of archaeological items.

Supplementary material related to this article can be found online at doi:10.1016/j.daach.2018.e00078.

1.3. Research aim

The study presented in this article was aimed at analyzing the application of four different scan systems in a Neolithic dolmen context, a structured light scanner in combination with photogrammetry for detailed documentation of commingled human remains, and three laser scanners to obtain detailed 3D images of the different construction stones, for archaeological excavations. The practicability of the scanning systems is reliable as they are routinely applied at crime scenes and accidents.

The key question however was the applicability of the structured light scanner and different laser scanners for scanning the more detailed interior and less detailed exterior areas of the Neolithic dolmen respectively. The aim is to present the two acquisition methods in the context of the excavation of the Neolithic dolmen of Oberbipp and discuss the advantages and disadvantages of both methods, the applicability to archaeological excavations and for subsequent studies.

2. Material and methods

Depending on the amount of detail and the surface texture of the material in question and the resolution of the different scanners, a scanning system was chosen (Table 1). Not all 3D documentation technologies are able to process for instance dark or reflexive textures and have different scanning requirements to gain optimum results (Table 2). The GOM ATOS III system (structured light scanner) has the highest resolution and therefore, it should be used on highly detailed materials. The three laser scan systems (ZF IMAGER 5010 ®, FOCUS 3D 120 and FARO ScanArm® Quantum V3) have lower resolutions and hence are less suitable for highly detailed materials.

Photogrammetry and the GOM ATOS III scanner were used to document the surfaces of each excavation level inside the dolmen (a ~ 2 m^2 area and five levels in total). For the construction stones and the outer areas of the dolmen the three laser scanners were used, as those work with lower resolution and accuracy, but still enough for our purpose, which increased the recording time (Table 1).

Table 1
Used measuring methods and systems. The application is referring to the areas of the dolmen.

Measuring method	System	Supplier	Application
Photogrammetry	TRITOP	GOM (Braunschweig, Germany)	Inside
Structured Light	ATOS III	GOM (Braunschweig, Germany)	Inside
Laser scan	ZF IMAGER 5010	Zoller + Fröhlich (Wangen, Germany)	Outside
Laser scan	FARO Focus 3D 120	FARO (Lake Mary, Florida, USA)	Outside
Laser scan	FARO ScanArm® Quantum V3	FARO (Lake Mary, Florida, USA)	Outside

Table 2
Summary of positive and negative aspects of the used 3D scanner.

Scan system	Pros	Cons
ATOS III (Volume scanner)	High resolution, high accuracy	Requires darkness, not battery operated, need to coat some surfaces, difficult to handle outdoor
ZF IMAGER 5010 (Spherical scanner)	− 10 to + 45 °C, usable for remote areas & all light conditions, large scanning range	battery life > 3 h, non-condensing
FARO FOCUS 3D 120 (Spherical scanner)	Small & light, usable for remote areas, large scanning range, colour scans, easy data management, battery life ~ 5 h	5–40 °C, non-condensing, fixed position
FARO ScanArm Quantum V3 (Line scanner)	Small & light, possible to scan dark and reflective surfaces, Wireless scanning, usable for small objects	10–40 °C, non-condensing, fixed position, constrain at an 7 axis arm

Table 3
Basic information about the four different 3D scanning systems used in this study. Comparing the different systems is difficult due to their different acquisition methods. [h]= horizontally, [v]= vertically; °= resolution depending on distance of scanner to the object.

Scan system	Range [m]	Ranging error [mm]	Scanned area/line	Resolution	Scan rate	Peculiarity
ATOS III	0.47–0.98	< 0.05 (this study)*	500 × 500 [mm]	0.24 mm	Up to 4 mil. points/scan	Darkness
ZF IMAGER 5010	0.3–187	≤ 1	360° [h] 320° [v]	°	1.016 mil. pixel/second	Fixed-point-net
FARO FOCUS 3D 120	0.6–120	± 2	360° [h] 305° [v]	°	976.000 points/second	Fixed-point-net
FARO ScanArm® Quantum V3	0.0–0.085	± 0.035	34–60 [mm]	0.054 mm	19.200 points/second	Constrain at an 7 axis arm

2.1. Documentation of the outer area and the construction stones

2.1.1. Z + F IMAGER 5010®

This scanner was designed for flexible close- and mid-range field use (Table 3). A scan took between two to seven minutes. Scans from 5 different positions were required to obtain the necessary area of the dolmen. The scans were then registered by the software Z + F Laser Control® 8.2.1 via the visible targets on each scan.

2.1.2. FARO FOCUS 3D 120

The FARO FOCUS 3D 120 works similarly to the Z + F IMAGER 5010® scanner (Table 3). It was also designed for documentation and measurements in the field such as construction sites or crime scenes. In this study, the equipment was used to establish the position of the construction stones. A fix-point-net has to be established using a total station which can be included into the excavation coordination system. The targets for the FARO FOCUS 3D 120 have to be placed on the beforehand established fix-points.

In total ~ 10 scans were required to cover the construction stones of the dolmen. Each scan took about 20–30 min. The scanner specific software FARO Scene (version 5.0) embedded the scans into the excavation coordination system.

2.1.3. FARO ScanArm® Quantum V3

The FARO ScanArm® Quantum V3 (Table 3) is mainly used in industrial settings. The position of the sensor is defined by the known lengths of each individual segment and incremental measurement systems, resulting in a constant orientation of the laser. Hence, no active set up of coordinates is required.

This scanner was applied for scans of individual stones that had been removed from their context prior to the excavation, with the intention to reposition them in the 3D model at their probable original position within the dolmen (Fig. 3).

Fig. 3. The FARO ScanArm® Quantum V3 used to scan one of the smaller stones of the dolmen.

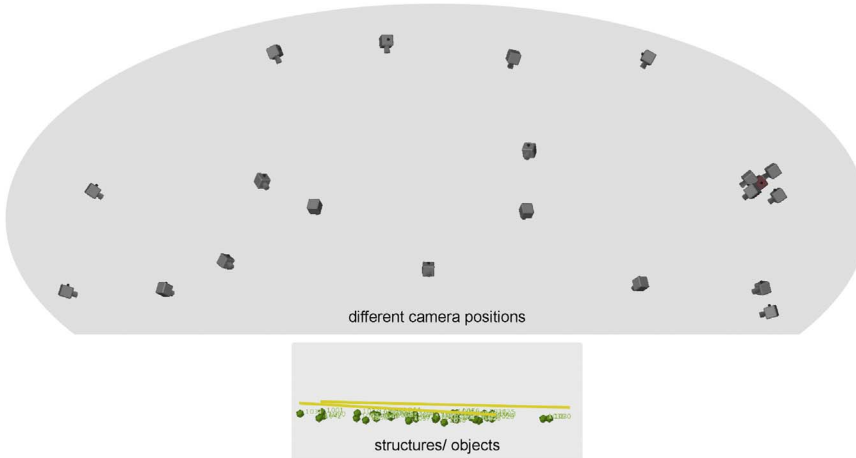

Fig. 4. Photogrammetry; different camera positions to document a single layer of the excavation surface.

2.2. Documentation of the inside of the dolmen

2.2.1. Photogrammetry

The camera position of the different photographs should ideally give a mushroom shape (Fig. 4).

The software GOM ATOS Professional (V7.5 SR1) recognizes the coded reference markers of each photograph, allocates the provided marker ID to each one, and combines the photographs.

In a final step, the bundle adjustments were calculated to evaluate the positions of the non-coded and coded references marker as well as the camera positions. Highly accurate calibrated scales provide the necessary dimension for the structured light scanning process which also requires the coded markers according to the photogrammetry.

2.2.2. GOM ATOS III - structured light scanning

Scanning took place at night due to the requirements of a structured light scanner (Table 2 and 3). The two camera lenses of the scanner have to detect the structured light pattern, which is produced by the projectors.

The scanner was calibrated for a measuring volume of 500 mm. The software GOM ATOS Professional (V7.5SR1) calculated a 3D coordinate for each pixel recorded by the sensors (located behind the camera lenses), in this case four million pixels per scan of 0.25 mm apart were calculated.

In a case like the dolmen, where the object is larger than 500 mm, it has to be scanned in several steps. In this study, for each layer more than 50 scans were required to cover the whole area. Each scan can be added to the previous one via the before defined reference markers of the photogrammetry resulting in a complete, detailed, and textured surface scan of the interior of the dolmen.

2.3. Combining the different scans

In a final step, the obtained meshes of the different scans were mixed to obtain the overall and final 3D model of the excavation surface. The model was orientated using the software GOM ATOS Professional (V7.5 SR1). After a manual orientation of the shared points of the different scans, a best fit analysis was used to transform the different scans into the local excavation coordination system.

In addition, the software 3DS Max (2009) was used to graphically visualize the different surfaces (Fig. 5). The software is able to provide a texture for a 3D model based on photographs.

Empty spaces visible on scans were not closed by interpolation algorithm, in order to represent only real scanned surfaces and to avoid falsification of surfaces.

Fig. 5. With the software 3DS Max generated textured 3D model from an area of the inside of the dolmen.

3. Results

Based on different scans and the photogrammetry, excavation plans and animations were created (Fig. 6, Animation 1). The three laser scanning systems for the outer area of the dolmen and the construction stones were applied depending on the accessibility of the material, the technical capabilities of the scanners and the details required (Table 2 and 3). The usability of the three scanners for the different materials in question was given as they provided excellent results. A direct comparison however is difficult as different preconditions due to the material and the scan system itself are given.

With the arrangement of five stations, the area outside of the dolmen was scanned (Z + F IMAGER 5010®) without difficulties as each scan only took a few minutes and repositioning of the Z + F IMAGER 5010® was easily feasible. The same applied to the FOCUS 3D 120, which had to be repositioned approximately 10 times to scan the construction stones of the dolmen in their entirety. Each scan was done within 20–30 min. Repositioning of the FARO ScanARm® Quantum V3 was not required as the small stones were placed directly in front of the scanner (Fig. 3).

A key question was the applicability of the GOM ATOS III for scanning the more detailed interior of the dolmen. Using the GOM ATOS III it was possible to document a single layer of the inside of the dolmen within less than a night, which increased the documentation process drastically without losing information.

The applicability of the GOM ATOS III was challenging due to its more complex repositioning process and the requirement of more than 50 recordings from different angles to fully cover the excavation surface within a few hours.

All scans were referenced into the local excavation coordinate system and overlapping of both scanning systems was used to transform the structured light scans into it. The recording of grave goods and artefacts with a surveyor's level and a total station made it possible to include those into the 3D model of the dolmen (Fig. 7, Animation 2). Hence, a detailed 3D animation of the excavation site including the archaeological records and associated findings was produced.

Additionally, the virtual reconstruction and repositioning of elements of the dolmen became more rapid due to the excellent quality of documentation. As the dolmen was found in slight tilted position, the 3D data were used to reconstruct its most likely appearance during

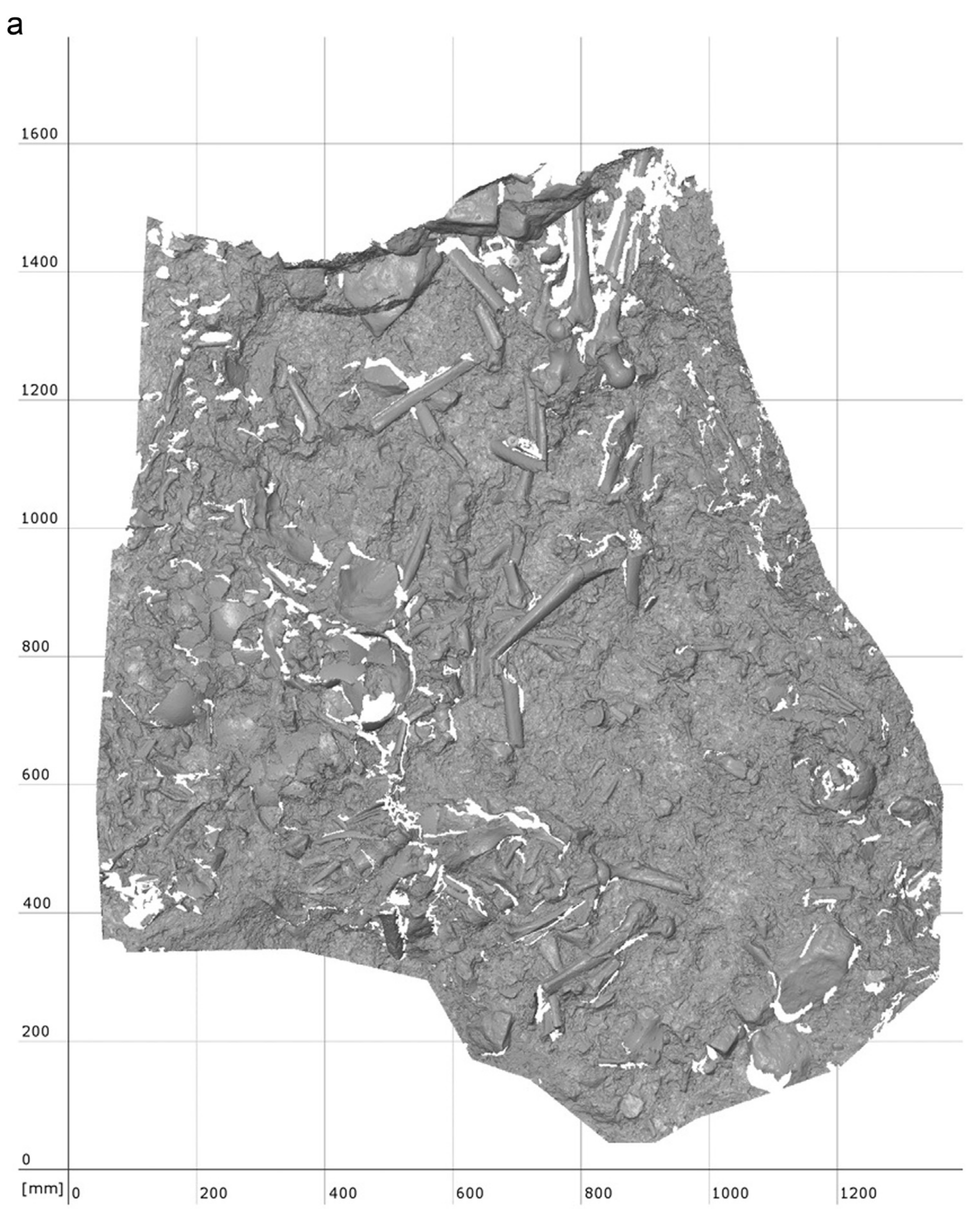

Fig. 6. Scan and corresponding drawing of one layer. a) The scan of first excavation surface, b) associated drawing of the first scan.

b

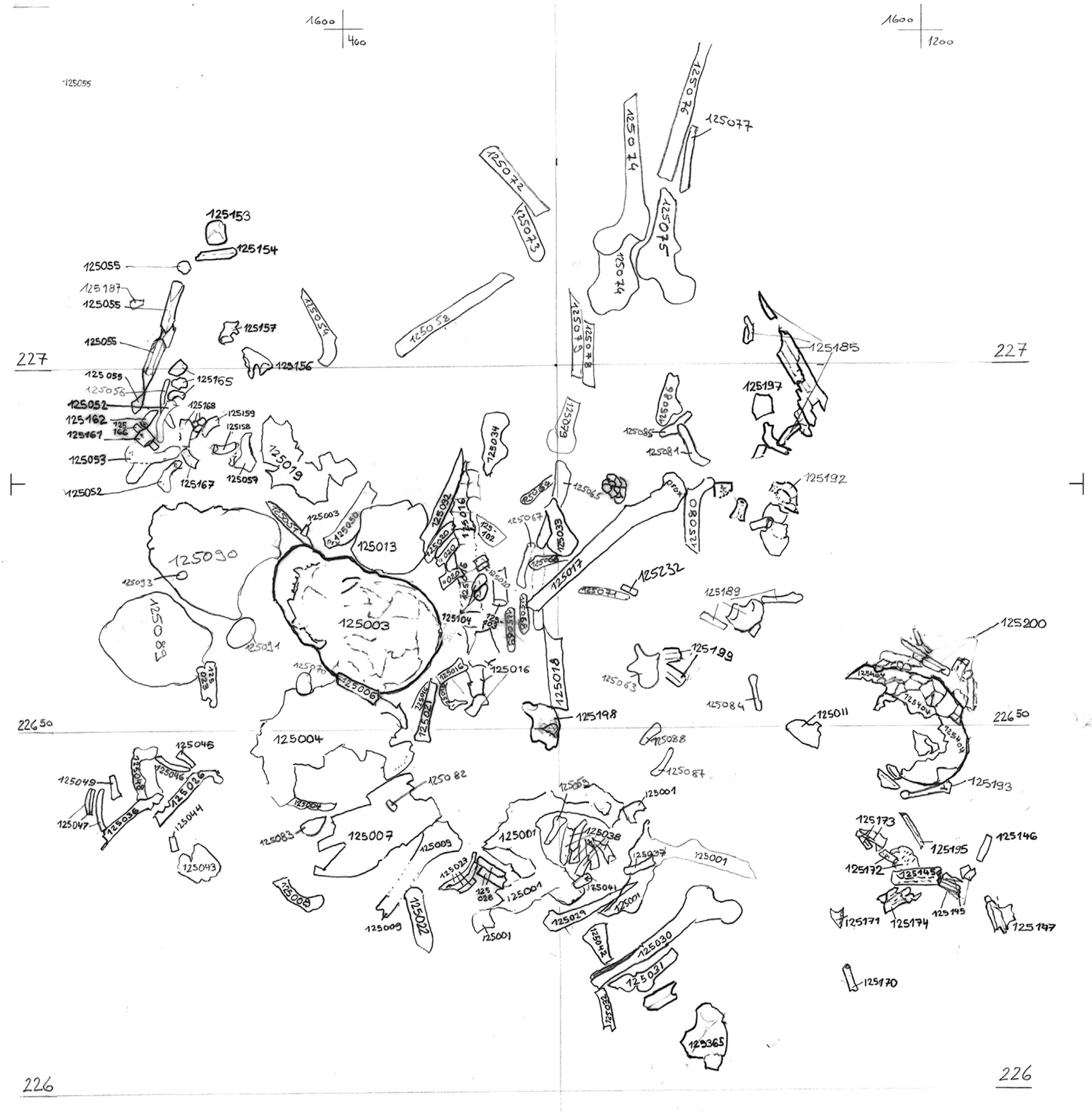

Fig. 6. (*continued*)

prehistoric times (Fig. 8, Animation 3).

Supplementary material related to this article can be found online at doi:10.1016/j.daach.2018.e00078.

4. Discussion

During the excavation of the dolmen in 2012 the use of 3D scanning equipment and technologies provided to be a quick way to recover the collective burial site and simplified the documentation process as time consuming scaled drawings were traced based on the 3D scans (Fig. 6). In particular, the human remains were well-documented providing comprehensible information of the inhumations, resp. the individuals bones. It was the first time that 3D documentation methods were applied to a collective burial site in Switzerland. The original appearance of the Neolithic dolmen at the time of use was reconstructed and a detailed 3D animation was established based on the scans (Animation 3).

We suggest the application of the Z + F IMAGER 5010® and the FARO FOCUS 3D 120 or successor models for large scale scanning, such as overview scans of the excavation site where less details are required. While scanner like the FARO ScanARm® Quantum V3 showed to be practicable for intermediate- and small-scale scans,

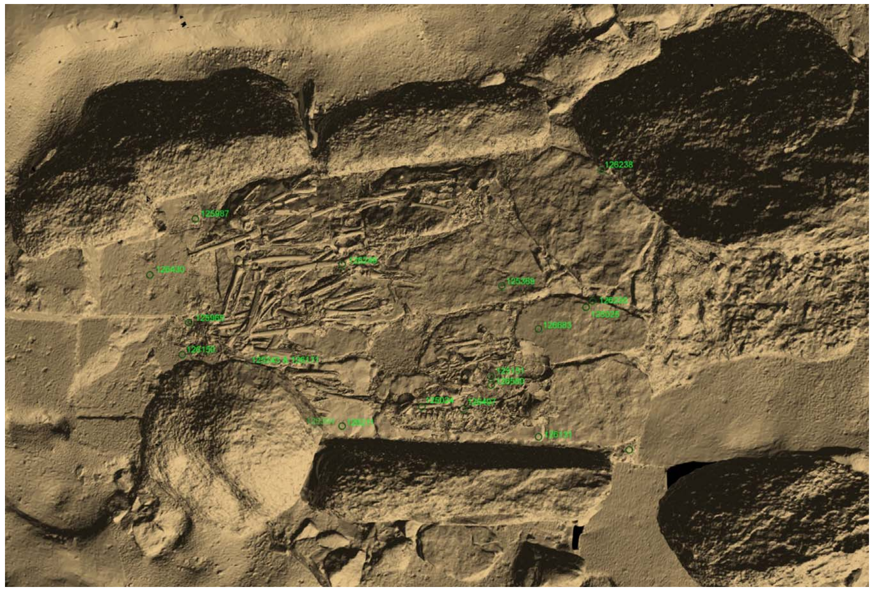

Fig. 7. An excavation level including the positions of grave goods and artefacts.

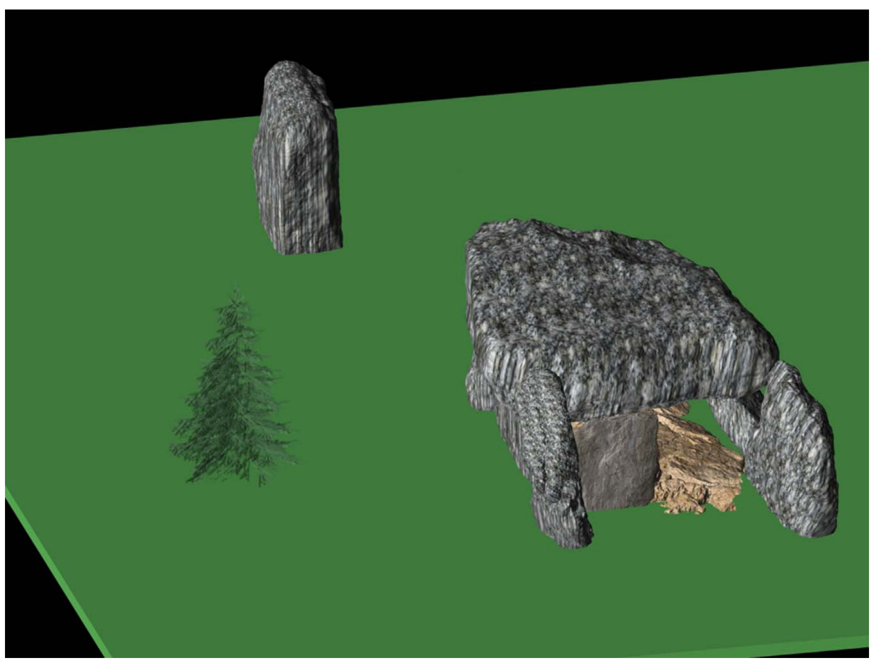

Fig. 8. Reconstruction of the most likely appearance of the dolmen, looking at the entrance.

respectively. It is suggested to use the FARO ScanARm® Quantum V3 for small objects that can be placed in front of the scanner. For archaeological purposes, it would be an ideal indoor scanner to document archaeological findings. The GOM ATOS III on the other hand is a reliable high resolution scanner. It is less beneficial on archaeological excavations due to its high effort of handling (requires darkness, difficult to reposition, Table 2). However, for the documentation of archaeological findings where great amount of detail is requested the GOM ATOS III would be the best option. We think that nowadays a hand-held scanner or Photogrammetry with Agisoft would be the best choice for such an excavation. Table 4 summarizes the pros and cons of conventional archaeological methods and different 3D documentation. The three laser scanners provided excellent results, their handling was easily feasible and all were highly time efficient. Even though the results of the GOM ATOS III proved to provide exceptional results as well and the documentation time was reduced drastically, the handling of it was slightly more challenging (Table 2). The conditions at the excavation site, a dolmen with commingled human remains, made it difficult to reposition the scanner in order to cover all angles of the surface. Two approaches were established to do so, however both provided certain limitations: for the first one, the scanner was fixed on an about 70–80 kg steel stand with outrigger. This resulted in a complicated procedure to reposition the scanner on the uneven excavation area (Fig. 9). The second method involved a tripod to fix the scanner, which made the repositioning process easier. However, as no side arm was associated with the tripod, the calibration of the scanner was more time consuming. Another challenge using the tripod arose when scanning perpendicular as the legs of the tripod partially covered the scanning area.

Whatsoever, those aspects are assessed as minor issues as the overall documentation time was drastically decreased and by the constant development of technical equipment they will be overcome

Table 4
Summery of the different documentation systems used at the excavation with their positive and negative aspects.

Methods		Pros	Cons
Archaeological methods (retain 2D information of the archaeological structures)	Individual altimetry	Quick and easy to use.	2D image, individual's points have to be added into the excavation plan; Difficult and cost-intensive to create altimetrical plans.
	Photography	Quick and easy to use; With specialized software (eg. AgiSoft Photoscan) a 3D image and plans can be created (SFM structure from motion); Conditions: larger quantity of images, use of photo markers to allow the software georeferencing.	2D image of individual structures.
	Detailed drawings	Detailed documentation of excavation site; Observations and descriptions of structures can be added on site.	Extremely time consuming; Less accurate; Puts archaeological artefacts and human remains at taphonomic risk due to longer exposition.
3D scanning methods (retain 3D information of the archaeological structures)	Photogrammetry	Provides large scale true surface images; "Normal" photographs can be used with the help of specific software.	Data management due to large amounts of data; No immediate control if bundle alignment works; No 3D live view.
	Structure light scanner	High resolution.	Data management due to large amounts of data; Operating in darkness; Difficult to be set up on site.
	Laser scanner	Small scanner available; Space requirement similar to individual altimetry or less.	Data management due to large amounts of data; Different temperature requirements.

Fig. 9. Difficult positioning of the GOM ATOS III fixed on an about 70–80 kg steel stand with outrigger, as it has to be stable and leveled.

in the future. Also due to the fast development of this technology, hand scanner and Structure-from-Motion photogrammetry are helpful tools to establish a 3D documentation of an excavation area. They are even more time effective and a hand scanner is recommended when space and time are limiting factors. Its small size and the flexible applications make it useful in space restricted areas and very time efficient while the resolution is still high. In addition, the advantage of the Structure-from-Motion is that it is affordable and has free available software (Westoby et al., 2012; Koutsoudis et al., 2014).

We conclude, that all scanning systems used in this study proved to be applicable at archaeological excavations in general (Table 4). The three laser scanners were easy to handle and produced true to scale results. Due to their wireless operational systems, they are ideal for remote areas such as archaeological excavations (Table 2). The structure light scanner was more difficult to handle but also produced highly accurate true to scale results (Table 2). Especially the highly detailed area with the inhumations showed exceptional results as individual bone features are visible, even in areas with densely pack bones, allowing reevaluation of finding situations of bone fragment during the morphological analysis. The amount of details would not have been possible to be recorded with simple drawings at the excavation due to the commingling situation and the high time demand for drawings. For remote areas where access to electricity is difficult the GOM ATOS III would not be practicable, however, hand scanner with high enough resolution could be used instead. In particular, extraordinary findings, such as the Neolithic dolmen of Oberbipp and with it the skeletal human remains, should be documented with the best applicable 3D documentation methods available. In our case, it was the GOM ATOS III structured light scanner for the more detailed structures of the dolmen interior. We would therefore highly recommend this system to colleagues for the documentation of detailed and complex structures. In addition, it should be used in conjunction with established archaeological documentation methods, as those are currently often still easier to access to other scholars and do contain the required information for subsequent studies. While 3D scanning provides new ways of documentation, its full potential in archaeology seems not yet reached, and it often aids as an additional method as in our case, to reduce the excavation time and store precise information about the finding situation (Table 4).

It is indicated that for highly detailed structures, e.g. delicate archaeological items, a structured light scanner or a hand laser scanner with a higher resolution rather than the laser scanner presented here should be used (Table 2 and 3). Furthermore, the choice of the scanner should be based on the processed object or area, the material (e.g. surface texture), the accessibility of the object or area, the required details of the surface (detailed object or overview scan for context of 3D model), the capability to process the data as well as, the available budget and time for the project. During the excavation of the dolmen in Oberbipp we could show that through the application of several scanning systems and scanners, depending on the requirements and the capacity of the scanners it is possible to obtain excellent results.

By means of the different scanning techniques, a 3D model of each relevant excavation layer, which is important for subsequent studies was generated by the ATOS III scanner and a visualization by 3 DS Max. In most cases, different investigators perform further analyses and thus they can gain an excellent overview of the finding situation by *scrolling* through the documentation (Animation 4). In our case, each layer of bones from the dolmen interior can be visualized separately for a detailed examination. Long bones for example, can be measured directly from the scan in case of degradation during recovery or cleaning of the remains. However, the management of the high amount of generated data, it is currently a limitation in itself, as data is currently stored locally which limits easy and independent access of different investigators. The argumentation that 3D documentation obtains information which are otherwise only locally stored as 2D data and often just accessible at the archaeological service themselves, is therefore currently not completely fulfilled. Koller et al. (2010) and Richards-Rissetto and Von Schwerin (2017) extensively discuss the developing issues of data storage and accessibility to actually retain all benefits that come with 3D documentation methods. Data management policies at different institutes or funding institutions also have to be adjusted in order to provide open access to obtained 3D data (Koller et al., 2010). We are currently not able to provide open access to our basic data other than the here published results.

In general, the obtained data provide sufficient and accessible information for subsequent studies, both for archaeological and anthropological analyses. Beside classical anthropological studies, biochemical investigations such as stable isotope analysis and ancient DNA will be performed in the future in order to investigate this population in the context of the central European Neolithic period. Another advantage of the 3D scanning methods is that they do not contaminate or impair the organic material, such as e.g. radiographic techniques, which is essential for ancient DNA investigations (Furtwängler et al., 2018).

Finally, beside a virtual reconstruction was performed due to the excellent quality of documentation, the 3D data could be used to rebuild the real dolmen in its ancient appearance. Consequently, this archaeological heritage became accessible for the public (Schlapbach, 2014).

5. Conclusion

Overall, it is concluded that unique archaeological discoveries such as a Neolithic collective burial site containing multiple inhumations and complex structures require state-of-the-art documentation methods to ensure the optimal recovery and preservation of the information. Additionally, those methods should guarantee that all information from the time of recovery is available to future generations of researchers and information loss is kept at a minimum. Nevertheless, this ideal practice is not yet reached, mainly due to limitations concerning digital rights management and storage possibilities.

Based on this study and given similar conditions to the here presented excavation, nevertheless, we recommend 3D scanning as a most useful tool for archaeological field documentation. We would recommend choosing the (combination of) 3D operating system(s) deepening on the following factors: accessibility of excavation site, the surfaces in question, the required resolution, usability of the data for subsequent studies, and state-of-the-art available systems.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.daach.2018.e00078.

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