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Eternal Witnesses—Documentation and Analysis of Carved Historic Graffiti and Inscriptions on Stone Surfaces

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Abstract

High-resolution documentation of graffiti carved into stone surfaces can help read nearly illegible characters. They can fade out due to outdoor conditions like weathering or biological coating. Indoor, the illegibility can be caused by delicately carved graffiti on a hard stone with a polished or shiny surface. These witnesses of people from former times are nonetheless important to tell stories about the place or object and help to enrich its history. This research aims to show how 3D scanning, especially structured light scanning, can help adequately document and analyse carved graffiti. Therefore, two case studies are discussed in this paper, highlighting different challenges while recording: an abandoned quarry in Bavaria, Germany, illustrating the problems of deteriorated surfaces with biological colonisation outdoors, and a gravestone in North Macedonia illustrating challenges occurring indoors with shiny, polished stone surfaces. The advantage of 3D documentation is, in both cases, to facilitate analyses, help researchers from different scientific backgrounds, and visualise and disseminate the results in a suitable way.

Keywords

3D scanning; Deterioration; Graffiti; Multilevel documentation; Stone surfaces

1. Introduction

To document particularly hard-to-read inscriptions and carved graffiti at cultural heritage sites, 3D technologies offer many advantages (Tenschert et al., 2018). To illustrate both the challenges and potentials of these techniques, this paper discusses two case studies of graffiti and inscriptions on different stone surfaces. First of all, the so-called Fingalshöhle, situated near Illesheim in Bavaria, Germany, holds dual significance as both an archaeological and a historical cultural heritage site (Bayerisches Landesamt für Denkmalpflege, 2022a, 2022b; Bayerisches Landesamt für Umwelt [LfU], 2022). The location is an abandoned sandstone quarry that has been gradually reclaimed by nature and the surrounding woods over the course of several centuries (Figure 1). The stones quarried here were used to build the town walls of a nearby city in the early modern period. Historical research indicates that even after the cessation of stone mining, the site remained in use during the Thirty Years' War (1618–1648) and later, from 1806 during the Napoleonic Wars (1804–1815), as a field quarters for German and French troops. During their stay, the soldiers carved many inscriptions, characters and dates into the sandstone walls. In the later 18th and 19th centuries, the abandoned site became a popular destination for visitors from the nearby castle and villages, who found in this place an example of the wild landscape, aligning with the ideals of the Romanticism movement of that era (Schultheiß, 1986).

There are many challenges at the site; the quarry is gradually disappearing into the surrounding wood, and the characters are being erased by ongoing deterioration due to moisture and biological coatings (Figure 2). Therefore, the site was recorded with a multilevel documentation approach using a combination of terrestrial laser scanning (TLS) and high-resolution structured light scanning (SLS). This approach will help preserve this remarkable location, along with its 300 years of graffiti and inscriptions in at least a digital form (Tenschert et al., 2023).

The second case study is the gravestone of St. Kliment, in Ohrid, North Macedonia (Figure 3). Sveti Kliment (English: Clement of Ohrid, ca. 840–916) participated as a disciple of Saints Cyril and Methodius in the Christianisation of the Slavs in Bohemia. After their return to the Bulgarian Kingdom, he became the first bishop of the Bulgarian Orthodox Church with his seat in Ohrid, where he founded the "Ohrid Literary School", writing and translating many works and educating thousands of young priests. Many important Old Church Slavonic manuscripts stem from the region as a result of his educational efforts. Kliment was canonised shortly after his death and is regarded today as the patron saint of Northern Macedonia. He was buried in Ohrid in a grave prepared by himself. Later, his grave was marked by a gravestone with an inscription that today is the only extant inscription and

Figure 1. Areal view of the Fingalshöhle in March 2023.

Figure 2. Section of the sandstone wall, highlighting the issues of biological growth.

Figure 3. The gravestone of St. Kliment in the chapel of the Perivlepta church in Ohrid.

gravestone for any of the so-called “Seven Apostles of the Bulgarian Orthodox Church” in a Slavic country. Prochor, an important successor to Kliment as an Archbishop in Ohrid, was given the honour of being buried and commemorated alongside Saint Kliment with the same gravestone (Kempgen, 2017; Knoben, 1974; Schäfer, 2020).

The gravestone itself is a narrow, largely undecorated stone slab, which today can be found in a chapel of the Perivlepta church in Ohrid. The flat and shiny stone carries not only the inscription dedicated to the saint but also another line of characters above. These characters have already been discussed in relevant Slavic research (Kempgen, 2017), but the exact content varies throughout the different sources and is probably subject to similar errors as the reading of the inscription of St. Kliment itself (Kempgen, 2016, 2017). Therefore, high-resolution documentation was needed to analyse the characters further.

2. Historic Carved Graffiti and Their Documentation

Carved inscriptions and graffiti have been popular but also challenging objects of study, as they vary considerably in terms of size, form and location. Whereas inscriptions are usually located, for example, on buildings (with a specified date) or tombstones, graffiti can be spotted almost everywhere. Graffiti encompass marks that are scratched, drawn, painted, or otherwise applied to various surfaces and can include characters, sketches or meaningless lines (Woolfitt & Fairchild, 2021). Historic graffiti hold great value as a source of information for the history or use of a building or site at a certain time and are sometimes the only witnesses of visitors, or means by which interventions can be dated. Consequently, they hold significant importance alongside inscriptions in understanding the complex history of cultural heritage sites. Traditionally, the process of documenting inscriptions and graffiti involved manual tracing with paper and pencil (Valente & Barazzetti, 2020). This technique can be used for graffiti or inscriptions big enough to be traced by paper and pencil and only on surfaces that are not endangered to be damaged by physical contact. Valente et al. (2019) mention this problem regarding graffiti on fragile fresco surfaces where contact should be avoided for conservation reasons. Therefore, non-contact technologies are preferable for these cases.

Newer digital technologies for the 3D documentation of carved inscriptions and scratched graffiti still face a wide variety of challenges. These can include the size and depth of the letters or drawings (Tenschert et al., 2023; Tenschert et al., 2018; Valente et al., 2019), the fragility of the surfaces, and even the material they are scratched in, as mentioned above, frescos (Valente & Barazzetti, 2020; Valente et al., 2019) or shiny, polished marble (Abate & Trentin, 2019; Tenschert et al., 2018).

A relatively common research activity concerning graffiti and inscriptions is deciphering and dating the characters or drawings, sometimes to decide whether the currently understood content and date are correct (Tenschert, 2019). In many cases, however, the main aim of (3D) documentation and research on graffiti and inscriptions is to make faded or faintly discernible scripts readable again, ideally using non-contact methodologies (Greco & Flouda, 2017; Papadaki et al., 2015; Tenschert et al., 2023; Tenschert et al., 2018).

2.1. Multilevel Documentation of the Fingalshöhle

While there are various ways of documenting locations with graffiti and inscriptions, for this specific case study and the numerous challenges of this unique site, a multilevel documentation workflow as described in Tenschert et al. (2023) was applied, including terrestrial laser scanning and high-resolution structured light scans. First, a Faro Focus S350 was used for 20 scanning positions to obtain an initial terrestrial laser scan of the entire area. Due to the size of about 1225 square meters and the complex shape of the five quarry walls, laser scanning was considered the most efficient method for capturing and recording the entire site (Figure 4). Each scan was carried out using the device’s parameters of 1/2 (resolution) and 2 (quality), resulting in approximately 174.8 million points per scan, with a 3D point distance of 3 mm at a distance of 10 m. The positions for scanning were selected to ensure coverage of all parts of the five main stone walls. Work was carried out in winter when the vegetation was less abundant to minimise the obstruction of the laser beam due to leaves and branches of the bushes and trees. The 20 individual scans were registered using the point cloud registration algorithm in Faro Scene software (Version 2020.0.7), and the recorded images taken by the scanner’s built-in High Dynamic Range (HDR)-camera used to texture the point cloud. Trees and bushes were manually removed from the 3D point cloud in areas next to the stone walls to increase the quality of the resulting point cloud. In addition, points recorded at a sharp angle to the walls were manually erased to reduce surface noise and improve the visibility and clarity of the graffiti and inscriptions (Tenschert et al., 2023).

In addition, high-resolution structured light scanning data of characters and writings that are barely readable or threatened due to their exposed location were recorded (Tenschert et al., 2023). An Artec EVA scanning device with Artec Studio 15 software was used to carry out the high-resolution scanning of these more delicate graffiti and inscriptions (Figure 5). The settings ensure a 3D point distance of up to 0.2 mm, though depending on the surface, a point distance of 0.5 mm to 1.0 mm was more likely (Artec3D, 2020). The device and resolution were chosen for this case study to ensure that the recording can be performed outdoors without a power supply and that even filigree scratchings are properly recorded. The approximately 30 most vulnerable graffiti and

Figure 4. Point cloud overview of the 1225 m² area of the abandoned quarry; the point could serve as a basis for a ground floor plan and as a general 3D documentation.

inscriptions were documented while the area of interest was in shadow, or using an umbrella to shield the surface from bright sunlight. The filigree organic structures (moss, algae and lichens) on parts of the inscriptions and graffiti covered with organic material, particularly in moist areas, were particularly difficult to capture. To enhance the quality of the surface model from the software's sharp fusion algorithm, the post-processing of each data set in Artec Studio 15 was carried out with a global registration followed by outlier removal (Tenschert et al., 2023).

Figure 5. Conducting the 3D scan in the Fingalshöhle with the Artec EVA.

2.2. High-resolution SLS of the Gravestone of St. Kliment

In May 2023, a Comet L3D 5M from Zeiss Optotechnik (formerly Steinbichler Optotechnik) was used for the three-dimensional measurement of the surfaces of the gravestone of St. Kliment. While not handheld, this SLS device is nevertheless portable and thus can be used on-site; it is particularly effective when used indoors (away from direct sunlight). The measurements are entirely contactless with only a projection of blue LED light, and are thus harmless to the stone surface. Although it is susceptible to the slightest vibrations and changes in light, the device scans the surface with exceptional accuracy and geometric detail. This method has proven to reveal even the finest details in the sub-millimetre range and measure tiny changes in cultural

Figure 6. Scanning the gravestone of St. Kliment in Ohrid using the Comet L3D 5M with two different resolutions and, therefore, different areas to capture, left: 260 mm x 215 mm at 0.1 mm point spacing, right: 74 mm x 62 mm at 0.03 mm point spacing.

heritage objects over time (Bellendorf et al., 2022; Degrigny et al., 2020; Rahrig et al., 2018).

The Comet L3D 5M was used because of its flexibility regarding the resolution; by changing the pair of lenses on the sensor, the measuring field of the scanner can be adapted to the desired surface resolution. The entire gravestone was recorded with the 250 mm lenses, which can record an area of 260 mm x 215 mm (with a depth of field of 140 mm), yielding a mean point spacing of 0.1 mm (Figure 6 left) (Steinbichler Optotechnik GmbH, 2014). In total, the recording consists of 46 individual scans, taken with an overlap of more than 50 %. This part of the gravestone was recorded in higher resolution to ensure that the delicate characters on the top of the stone could be analysed with the highest possible accuracy. These 21 scans were performed with a second set of lenses, ensuring a 3D point distance of 0.03 mm while covering an area of 74 mm x 62 mm (with a depth of field of 45 mm) per single acquisition (Figure 6 right) (Steinbichler Optotechnik GmbH, 2014). It was decided to use a structured light scanner that specialises in highly accurate acquisition of the stones' surface geometry, since the texture information is not needed to analyse the characters further (see also Tenschert et al. (2018)). Without the texture information, the surface structure is more obvious and can be virtually investigated in great detail using raking light generated with artificial light sources. Due to the high-resolution documentation of the surface topography in the sub-millimetre range, surface features of the strokes of the characters can be detected and analysed precisely to ensure a correct transcription.

The CometPLUS v.9.96 software processed the scans, performing a constrained matching calculating an iterative-closest point matching (ICP/'best-fit') and mesh building algorithm. The mesh resulting from the triangulation process was imported into Geomagic Wrap v.2021 to align the model orthogonally along a plane to simplify the export of views. After aligning the models, they were imported into the Aspect3D v 16.5 rev. 8586 (Arctron GmbH). Using this software, orthoimages were generated at a scale of 1:1 and 900 DPI under artificial raking light to highlight the surface structures.

3. Discussion and Results

As discussed by Valente et al. (2019), scratched graffiti can be extremely difficult to document, because of the main problems like the small size of the scratchings and the poor visibility due to unpleasant surface conditions, e.g. physical lacks, and unfavourable lighting conditions. Another main issue Valente et al. (2019) mention is the presence of different overlapping layers of graffiti, which makes it hard to separate the strokes. In the case of the quarry, these difficulties are caused not only by poor visibility due to outdoor lighting conditions (shade, sunshine) but also by bad stone surface conditions, moisture, minimal scratch depth, multiple layers of writing and, particularly in this case, the growth of lichen and moss and natural erosion. To use close-range photogrammetry (Samaan et al., 2016; Valente & Barazzetti, 2020; Valente et al., 2019) for the vulnerable graffiti and inscriptions was considered especially due to its flexibility regarding the camera used and the cost efficiency, but ultimately, it was decided to use SLS with the above-mentioned device and software. This ensures real-time feedback, and it could be verified on-site whether the recording was sufficient and successful. Using RTI (Reflectance Transformation Imaging), as suggested in previous research (DiBiasie Sammons, 2018), was considered but considered impractical due to the outdoor environment with uncontrolled lighting. DiBiase Sammons describes this single camera multiple light positions method as suitable for smaller graffiti that can help to decipher them (DiBiasie Sammons, 2018). As the method depends on controlled light settings, it is not so efficient outdoors. Valente et al. (2019) mentioned that even indoor conditions with ambient light can decrease the effectiveness of the RTI method. The position of the gravestone of St. Kliment was a determining factor as well, as the lack of space in the narrow corner where it is situated was deemed too impractical for RTI. The handheld SLS scanner mentioned above was also considered; however, the accuracy and precision of the Artec EVA scanner (as well as the more accurate device from the same manufacturer, the Artec Space Spider) were found to be insufficient to detect the delicate carvings on the gravestone.

3.1. The Graffiti and Inscriptions of the Fingalshöhle

The written testimonies to this site's diverse history are today threatened by the ever-increasing encroachment of the surrounding wood into the abandoned quarry and, above all, by unavoidable weathering processes affecting the unprotected stone, which will only be intensified by the effects of climate change in the future. Some photographs of the stone walls show that even over periods as short as the last 10–15 years, climatic effects have completely obliterated some of the graffiti and inscriptions. In addition, the growth of moss and lichen on stone exposed to an outdoor climate is a well-known problem for cultural heritage (Bertolin, 2019; Cozzolino et al., 2022; Daly, 2019; R. Drewello, 2004; R. Drewello & Drewello, 2009; U. Drewello & Drewello, 2013; Wilhelm et al., 2020). The main problems of the stone walls, as categorised in the ICOMOS glossary on stone

Figure 7. Area of the stone walls of the Fingalshöhle showcasing deterioration caused by weathering and the overgrowth with lichens, algae and moss.

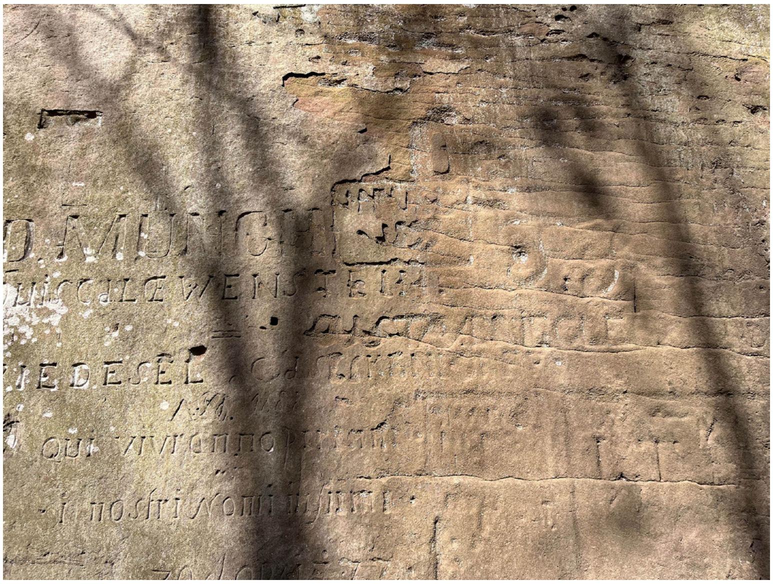

Figure 8. Area of the stone walls of the Fingalshöhle showcasing deterioration caused by weathering and water drainage.

Figure 9. Orthophoto of an area of the 107 meters of stone walls of the Fingalshöhle, showcasing graffiti readable in the TLS-data (left and right), also visible are the moist areas in darker grey.

deterioration patterns (ICOMOS - International Scientific Committee for Stone [ISCS], 2010), are erosion, mechanical damage and biological colonisation, as well as moist areas due to water drainage (Figures 7 and 8). Because of these ongoing deterioration processes, the graffiti and inscriptions in the former quarry are slowly but steadily being erased.

The aim of this work is, as already mentioned in Tenschert et al. (2023), to create a basic documentation which should preserve, at least in digital form, the current state of the cultural heritage site since the deterioration and decay could only be stopped with massive interventions to the quarry itself, for example, the construction of a roof. The documentation will enable further research and allow future generations to experience and explore this multi-layered site.

As mentioned in Tenschert et al. (2023), three stone walls show different kinds of inscriptions and graffiti: The size and arrangement differ widely, as well as the depth of the carvings. Whilst some of the characters and sketches are quite delicate and filigree and are therefore nearly invisible today, others are scratched very deeply into the sandstone and can even be read in the TLS data (Figure 9). Some inscriptions are very well arranged with small sketches or drawings, for example, a group of writings with a military theme that serve as witnesses of the quarry's use as quarters for both German and French troops (also described in Schultheiß, 1986; Tenschert et al., 2023). Some of the graffiti and inscriptions are dated, and some just give a name. There are numerous inscriptions and graffiti, and one can also find traces of installations and many bullet holes in the area of the quarry, illustrating the site's usage and history in times of war. Some inscriptions and graffiti are clearly visible, but many are unreadable either in photographs (with raking light) or with the naked eye. The content of these examples of carved witnesses was only revealed using the high-resolution scanning data from the SLS. On the other hand, the larger and deeply scratched graffiti and inscriptions can be read using the orthophotos from the TLS point cloud. The inscriptions and graffiti on the stone walls have neither a specific order nor systematic arrangement, and some even overlap (Tenschert et al., 2023). Particularly interesting are the writings from visitors during the 19th century that can be addressed as graffiti: The visitors immortalised themselves with engravings in a great variety of ways. The writings often include a name and sometimes a place where the person came from, so one can begin to tell the story of the people visiting this place over time (Figure 10). There are also graffiti from the 20th century with mainly the name of the visitor and the year. The last group generally seems to take less

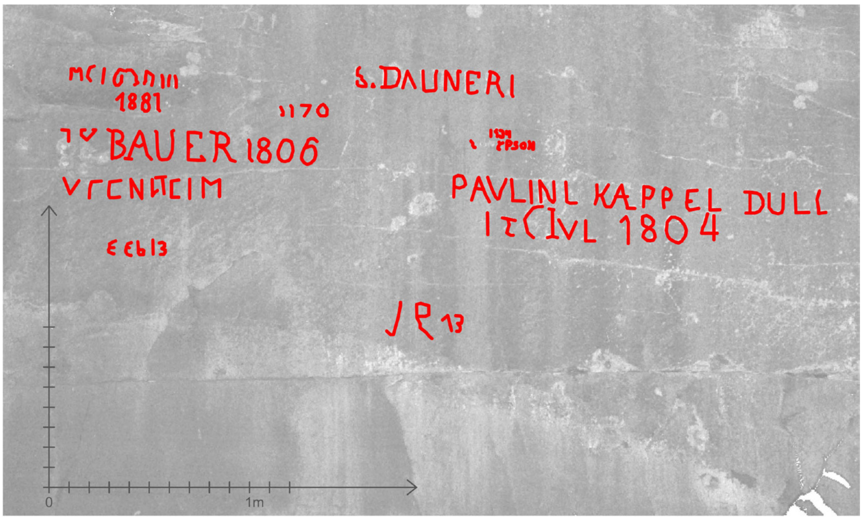

Figure 10. Orthogonal image of the TLS- data with transcription of the readable graffiti, showcasing on the left that a person called Bauer from Uffenheim (a village in Bavaria) visited the site in 1806 (see also Tenschert et al. (2023)).

Figure 11. Graffiti mentioning "H. v. Seckendorff" and the more delicately carved "G. Krahiser v. Sontheim" above, unreadable in photographs with different lighting and moisture conditions.

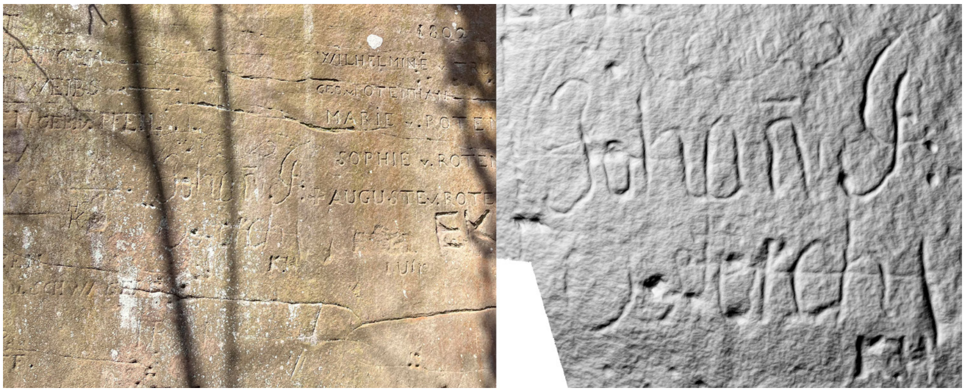

Figure 12. Graffiti quoting Johan F. Osterch. Comparison of the barely readable photo with the 3D model.

account of existing inscriptions than the others. They are sometimes even written over existing letters (Tenschert et al., 2023).

With the help of the 3D documentation, it was possible to rediscover some previously lost graffiti and inscriptions. An example of a nearly unreadable graffiti is shown in Figure 11: Above a deeply scratched graffiti, mentioning "H. v. Seckendorff", there is another with more delicately scratched characters mentioning "G. Krahiser v. Sontheim" (Sontheim is a nearby village) (Tenschert et al., 2023). The Seckendorff family is an old noble Franconian family and the

Figure 13. Graffiti quoting L. SchAUMAN. Comparison of the barely readable graffiti in a photo and in the orthophoto of the 3D model.

H. v. Sekkendorff mentioned might have been serving in the Bavarian army (Pierer, 1862).

Another example is a graffito with the words "Johan F: Osterch" (Figure 12). Due to the progressive erosion and the growth of lichen, especially in the lower half of the picture, it was difficult to decipher the letters. To the right and below this graffiti, the letters "K" and "H" could also be made out, as well as a curved line above, which, only recognisable in the 3D model, contains an "M".

Another example is letters that can be combined to form "L. SchAUMAN", but both moss and lichen combine to make the lower area barely legible (Figure 13). In the 3D surface model, however, further letters can be recognised, which could indicate the name of a place or of another person.

3.2. Gravestone of St. Kliment

The gravestone itself, a variety of marble or soapstone, was difficult to record due to its shiny surface, and the

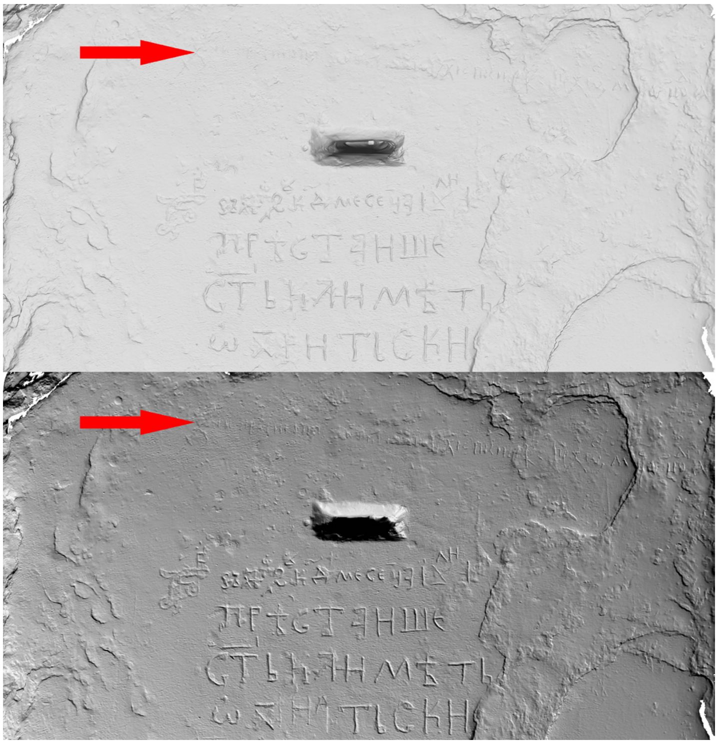

Figure 14. 3D model of the gravestone of St. Kliment. Above illustrated without artificial raking light with a mean point distance of 0.1 mm, below with raking light at the same resolution, the original inscription is clearly visible, the line of characters with the second epitaph starts at the red arrow.

Figure 15. 3D model of the line of characters with higher resolution (3D point distance of 0.03 mm) cut in the middle and illuminated artificial raking light to ensure the characters can be read. Red: Cyrillic characters and English translation.

various colours of the stone made reading the characters nearly impossible with the naked eye. The characters are not scratched deeply into the stone surface, and the single strokes are filigree. Similar to the Graffiti in St. Naum, this combination of shiny surface and delicate carving proved difficult to record (Tenschert et al., 2018). These challenges can lead to an insufficient or incorrect reading of the letters.

With the textureless high-resolution 3D models, it is now possible to investigate the characters in great detail without complications caused by the surface colour. The slight, wave-like noise in the 3D data cannot be avoided due to the stone structure and shiny surface, but it is negligible and does not affect the Slavists' evaluation and the readability of the characters. Therefore, this kind of documentation can contribute to clarifying the meaning of the characters.

On the gravestone of St. Kliment of Ohrid (840–916), whose epitaph (from the 14th century) was the primary focus of attention in the project, there is a second epitaph at the top of the stone dedicated to Archbishop Prochor of Ohrid (tenure 1528–1550), which was therefore engraved much later (and much smaller) (Figures 3, 14 and 15). Apparently, the archbishop was also buried here, because the Perivlepta Church was the city's main church at that time (during Ottoman rule) and thus Prochor's place of activity. The characters can be seen in a photograph with improvised lighting, but the problems are immediately apparent; reading the text properly is impossible. The exact contents of this line have been widely discussed in the relevant literature, but its reading in the various sources varies and is probably subject to similar errors as the reading of the inscription of St. Kliment itself (Kempgen, 2016, 2017).

The content is thus clear in principle, but the exact reading remains to be checked, corrected and completed if necessary, as indicated by the bracketed parts. For example, such a formulaic inscription usually includes the date of death, which should appear at the very end. So far, there is no indication in the literature as to whether this number is still present or legible (Figures 14 and 15).

4. Conclusions

The multilevel documentation approach for the abandoned quarry employing TLS and SLS was deliberately selected to achieve comprehensive documentation of the entire archaeological and cultural heritage site while also providing detailed records of the most vulnerable and delicate graffiti. The chosen methodology allows future investigations and interdisciplinary research, especially in the face of weathering effects and damages caused by moisture and natural erosion of the surveyed quarry, which will likely lead to further deterioration over time. It was not only possible to record and document this unique site, but it was also possible to make some of the most vulnerable and faded-out graffiti readable again. These analyses can serve as a basis for future research on the visitors and the use of the quarry itself. Furthermore, this dataset can serve as a basis to monitor the condition, enabling the measurement of weathering effects.

Along with the objective of documenting the current state of the site in digital form, ensuring its availability for future generations, new clarities could be found about the characters above the inscription for the saint himself on the gravestone of St. Kliment in Ohrid. The stone surface was challenging to record, but the chosen device and method did lead to satisfying results suitable for further research. With the help of the high-resolution 3D surface model of the stone and the ability to investigate the characters more accurately than in a photograph, it was possible to prove—due to the help of virtual raking light—that the reading previously suggested by the Slavic research is correct.

The two case studies highlight that stone surfaces can be challenging due to different factors when exposed outdoors or indoors. Nonetheless, the 3D documentations enable analyses and further research. For future work, it is planned to share the data with the local administrations, the public, and researchers, storing them in a digital repository to make it available.

Conflict of Interest

The authors declare no conflict of interest.

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