THE MEMORY OF A 2nd WW CAMP: 3D MODELING USING THE COMBINATION OF HYBRID TECHNOLOGIES

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ABSTRACT:
The Natzweiler-Struthof camp is the only concentration camp in France, in Alsace. In 1941, when the construction of this camp began, the Nazi regime had already set up several concentration camps in annexed territory. The purpose of this camp was mainly to intern the resistance considered dangerous for the regime. From a chronological point of view, the camp integrated in May 1941 its first prisoners. They were condemned to carry out inhumane work until the evacuation of the camp on September 2, 1944. The Natzweiler-Struthof camp was associated with a granite quarry where we can still find concrete foundations of old buildings as well as three galleries excavated with explosives. The digitization work aims to archive, analyze and understand the organization and operation to result in a 3D reconstruction of the site. In 2018, the Struthof site began a major restoration project. For the first time in this camp, an archaeological diagnosis was then made with the aim of understanding the still existing facilities and assuming the presence of other elements now destroyed. To deepen the knowledge on this camp, the Regional Administration of Cultural Affairs authorized in 2020 to carry out prospecting accompanied by a study of the built-up in an area still empty of research: the quarry. Currently, this part of the camp shows the remains of three buildings and three galleries. To know more about these elements and indirectly about the life of the camp and its prisoners, this study shows the approach adopted to prepare the 3D modeling of buildings and galleries.

1. INTRODUCTION

1.1 Context of the study

The Natzweiler camp is located in the Vosges massif about 50 km southwest of Strasbourg. It was positioned on a site with a strong gradient on the village of Natzwiller (France, Lower Rhine) at the place called "Struthof". This location at an altitude of more than 710 m and the special climatic conditions have put a strain on the prisoners and the camp's facilities. The remains of the camp are organized into six large parts spread over thirty hectares (Figure 1): - the low camp, built around the Idoux farm (No. 1), - the high camp, the main area of the camp which includes the barracks of the deportees surrounded by a double fence, but also the housing of the SS, medical, administrative and workshop spaces surrounded by a third fence (No. 2), -the National Necropolis and the National Deportation Memorial built between 1957 and 1960 on the site of destroyed camp administrative buildings (No. 9), -the sandpit also used as execution place (No. 8), -the quarry for the operation of granite and then for the repair of aircraft engines for the Junkers firm installed above the high camp (No. 3 and 7), and -ancillary facilities (water tower, electrical transformer and powder keg) (No. 4, 5 and 6). The history of the camp develops into five main phases (Simon *et al.*, 1998; Steegmann, 2005; Brangé 2020). First used as an agricultural area, the tourist function developed at the end of the 19th century through the installation of a guesthouse near ski slopes and hiking starts. After the annexation of Alsace to the German Reich, the creation of the concentration camp decided by the Nazis in September 1940 began in May 1941 following geological exploration that led to the discovery of pink granite veins. The deportees, first housed in the low camp located around the pre-existing guesthouse, carry out the extensive earthworks allowing the installation of an access road, terraces, and shacks. They are also assigned to various other jobs such as extracting granite within the quarry, or dismantling aircraft engines for Junkers firm.

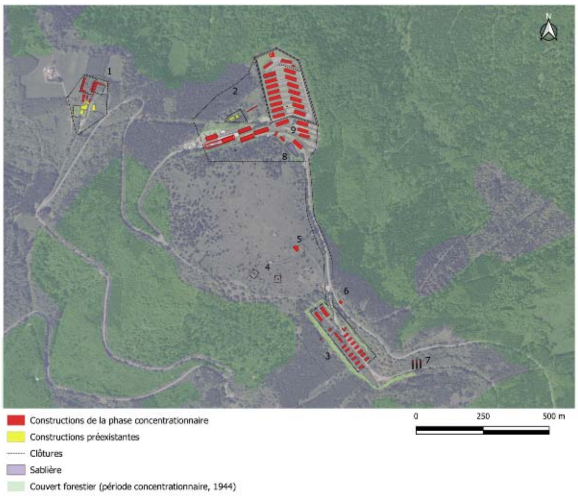

Figure 1: Camp map, state 1944 (J. Brangé, aerial photo IGN 2011).

A total of 52,000 deportees from nearly 30 different nations were deported to the central camp of the "Struthof" or one of its annex camps. About 22,000 of them lost their lives in this complex, bringing mortality to almost 40%, very high in view of the brief and late existence of the camp. The central camp has

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about 3,000 deportees in normal periods and up to 6,000 during busy periods. In September 1944, the camp was evacuated. A few deportees, housed in the quarry shacks, remain assigned to the maintenance of the camp. The French Militia fleeing to Germany briefly occupied the barracks of the high camp in September 1944. A few weeks later, on November 25, 1944, the U.S. Army discovered a functioning camp empty of its prisoners. From December 1944, an administrative internment camp opened its doors very quickly, under the responsibility of the French Ministry of the Interior, to lock up German civilians of the Nazi occupation administration, Alsatians accused of collaboration or militia men taken prisoner. The management of the camp was under the direction of the Ministry of Justice from November 1945 until its closure in January 1949. The aim is to "re-educate" young adults sentenced to long sentences. At the same time, there is a very rapid desire to transform the site into a memorial space, even if it is not always accompanied by a concern to preserve the entire remains of the camp. Some areas are safeguarded while others are destroyed or deeply transformed (Neau-Dufour, 2019).
Since the early 2000s, the camp has been the subject of heavy redevelopment and restoration campaigns. Continuing the research problems developed abroad in several Nazi concentration camps, mostly since the 1990s (Theune 2014; Bernbeck 2017; Haubold-Stolle *et al.* 2020) and the National Archaeological Research Program published by the National Council of Archaeology in 2016 (Baratte *et al.* 2016), the first preventive archaeological operation is being carried out at the “Struthof” in 2018 (Bolly and Jeanneret, 2019). Archaeological diagnosis identifies the remains of a now-defunct administrative barracks. Observations are also made at a watchtower and in the environment of the gas chamber.
In 2019, an archaeological follow-up carried out near a watchtower of the camp high allows to inform the stratigraphy of the fills related to the construction of the National Necropolis and the Memorial that have impacted the topography of this part of the camp. The concrete slab of the administrative barracks of the high camp apprehended in 2018 is also discovered fortuitously during earthworks. The remains, studied in 2020, allow us to better understand this shack that disappeared in 1950 (Landolt, unpublished). More recently in 2020, a preventive excavation has documented part of the access road to the camp (Bolly, unpublished). The different layers of construction of the track set up from May 1941 by inmates and civilian workers could be observed. At the slope of the track, a level of destruction was also apprehended, delivering a very large batch of objects.
In parallel with preventive archaeology operations, academic work carried out since 2019 has established a comprehensive inventory of the development of the camp with all the photographic and mapping documentation (Brangé, 2020). 220 expansions were identified. Each layout was thus able to be the subject of a critical description and study put into perspective with more than 450 iconographic documents. The interpretations and evolutions related to the different phases of camp occupation were thus apprehended. In 2020, this preparatory work was associated with an archaeological survey and a partnership with INSA which allowed to study a set of remains located at the quarry level by specifying the organization and evolution (Brangé *et al.*, 2021). Since 2021, all these studies have been integrated into a collective transdisciplinary research program and planned archaeological excavations will be developed in the coming years.

2. A SITE WITH SEVERAL COMPONENTS

The trigger for the construction of the Natzweiler camp was a report written on 14 September 1940, which reported the discovery of an excellent pink granite vein by the *SS-Standartenführer* Karl Blumberg. The Nazi regime had commissioned geologists to carry out geological surveys and thus find rock for architectural projects. From the outset, the desire to exploit the quarry is thus clear so that it is the presence of this rock that determines the creation and location of the camp near the work area.
In 1941, with the creation of the camp, a road of about 5 km was built from Rothau station to the quarry. 48,000 m^3 of land were displaced and 477,178 hours of work were then carried out (only 79,731 by the deportees). On the site, the first two buildings were built. In 1942, the development of the quarry's area continued for the work of the stones, requiring partial deforestation. The granite was cleared for 500 meters. Everything was put in place so that the deportees could start the extraction work and had space for the transport of the rocks.

Figure 2: Exploitation of the quarry in spring 1942 (Postcard ed. Lucien Kohler, CERD).

In 1943, with the transformation of the concentration system in general and the *Deutsche Erd- und Steinwerke GmbH* (*DESt*) in particular, it was all the work done at the camp that was modified. Quarry extraction activities are mainly in the hands of dismantling and retrieving aircraft engine parts for *Junkers* Firm. It should be noted that civilian workers are also present at the site. Deportee Germain Lutz recalls volunteering to build barracks erected at the entrance to the quarry. He was then assigned to one of these halls for unpacking and packaging instruments and mechanical parts. Subsequently, he was placed at a workstation in one of the engine dismantling halls (Lutz, 1998). From the summer of 1943, a dozen halls were used for the dismantling of Junkers aircraft engines and the recovery of parts still in working order to assemble new engines (Figure 3).

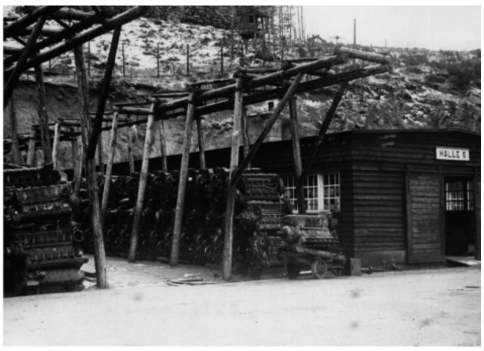

Figure 3: View of Hall 6 and stock of aircraft engines (CERD).

The engines of downed aircraft were transported by rail to Rothau station and then brought by car to the quarry site. The reusable parts were then shipped to the *Elmag-Lager* in Strasbourg, probably a storage store (*Elmag - Elssiche Maschinenbau GmbH*) (Lutz, 1998). Other inmates continued work on the rock and began drilling three tunnels to protect the workshops from shelling. But with the evacuation of the main camp in September 1944, *DESt* was forced to abandon its plans (Steegmann, 2005).

2.1 Global DTM from UAV images

As the project is focused on the ruined buildings and galleries, it is also necessary to survey the quarry area to have a global point cloud in which to integrate the different datasets. The goal would be to eventually obtain a digital terrain model (DTM) of the granite quarry by following the path with its close surroundings from the three underground galleries to the ruins.
Thus, we carried out a photogrammetric campaign with a DJI Phantom 3 drone equipped with a 12-Megapixel camera. With an interval of 3 seconds between each shot, nearly 2000 photos were captured at an altitude of about 30 m above the site. 32 targets were placed on the ground on the cleared areas, to allow georeferencing thanks to their measured 3D positions, with enough spacing to cover the nearly 700 meters of path travelled by the UAV. These photogrammetric targets were georeferenced by GNSS determination in the RGF93-Lambert 93 coordinate system. After acquiring the images, the photogrammetric processing was mainly performed on *Metashape*. *Agisoft Metashape* has the advantage of providing a wide range of automatic tools. We have for this project almost 2.000 photos that we had to sort and assemble in chunks to lighten and optimize the calculations of the software. Several steps were therefore carried out, starting with the identification, and marking of targets on the ground. It was necessary to manually reposition more precisely the marking of the numerous targets detected approximately by the software. Then, after the alignment of the photos for each chunk, we were able to associate the coordinates, taken on the ground with the GNSS in Lambert-93, to the various targets to geo-reference the project using the transformation calculated from the control points. The alignment allows the relative orientation of the images between them with the search for tie points as well as the internal orientation for the calculation of the camera parameters, not calibrated before.

Figure 4: Global DTM of quarry area.

Targets with an average error of more than 3-4 cm (calculated tolerance) have been placed as check points, or even deleted for some. It was necessary to make several tests by varying the parameters to obtain a satisfactory point cloud. The residues of the automatic calibration performed by *Metashape*, of the control and check points, of the point cloud and of the overall project, are listed in an error report generated by *Metashape*. The Figure 4 shows the whole studied area with the associated DTM.

2.2 Technical Buildings

The forge and depot were established at the northwest end of the quarry. They constitute an imposing set of symmetrical buildings. This was the first set of constructions that civilian workers could see at the entrance to the quarry along the path reserved for them. Despite their monumentality, these buildings have never been the subject of architectural study until now. Present on most of the camp's plans, no study of their internal distributions and developments had been undertaken. These aspects have only recently been raised in the context of academic work and archaeological exploration (Brangé, 2020; Brangé *et al.*, 2021). The forge building is a sign of changes in the quarry. Indeed, its construction during the summer of 1943 was closely related to the establishment of a Working *Kommando* assigned to the repair of aircraft engines for the firm *Junkers*. The building developed on two levels on a ground surface of about 530 m^2. With a rectangular plan and a north-west/southeast orientation, it is 40 m long and 12 m wide. A passageway and a staircase (30 m x 2 m) installed along the south-west façade allows attempt to access the various spaces. The building has been designed to adapt to the natural slope of the land and thus has two levels downstream and only one upstream. Thus, the ground floor occupies only the northwest half of the building and the floor extends the entire length of the building (Figure 5).

Figure 5: View of the southwest façade of the forge.

The archaeological study of the building gave new light on the understanding of the layout of the forge. Four fireplaces of an industrial-type forge, each with two workspaces, were identified (Figure 6).

Figure 6: Forge fireplace.

The remnants of the ventilation, heating, smoke, temper and typing system could be characterized. A Cyrillic alphabet graffiti made on the fresh coating of a base of the forge attests that a Soviet or Yugoslav deportee participated in the development of the forge during the concentration period. These evidences indicate that the work of the deportees was not limited to the dismantling of the engines and that work likely involving the repair and/or manufacture of certain spare parts was carried out directly on the site (Brangé *et al.*, 2020).

The depot's building began in August 1943. It was certainly completed in late 1943 or early 1944. This is the last building installed within the quarry. It was documented in a photograph from June 1944. The building developed on a single level on a ground surface of about 500 m^2. With a rectangular plan and a north-west/southeast orientation, it measures 40 m in length and 14 m in width. A passageway and a staircase (20 m x 2 m) installed along the north-east façade allow access to the interior spaces of the building. As with the forge, the building was designed to adapt to the natural slope of the land. Thus, the ground floor developed on three distinct levels. Traffic between the different levels is provided by a system of stairs and internal ramps (Figure 7). The archaeological study of the building brought elements to the interpretation of the installation as a storage space.

Figure 7: View of the northeast façade of the depot building (A. Vantillard).

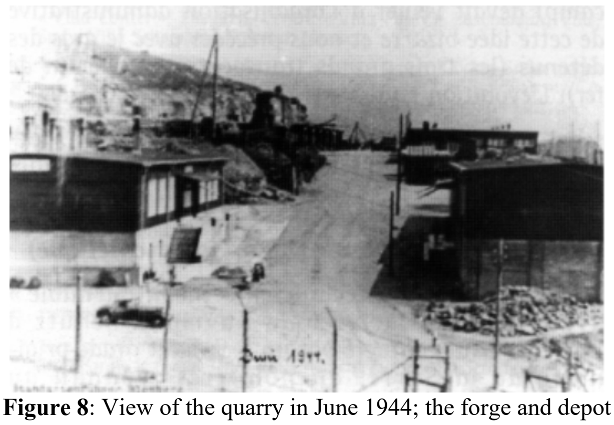

Figure 8: View of the quarry in June 1944; the forge and depot are the two buildings visible in the foreground (CERD).

Elsewhere, the distribution of the parts of the depot and the symmetry of the openings of the passageways of the forge and depot buildings allowed to propose the existence of a single-cable air transport system to transfer materials or heavy parts between the storage building and the forge.

Laser-scanner data acquisition: The goal was to survey the two industrial ruined buildings: the depot and the forge. These buildings were surveyed by indirect georeferencing with a FARO Focus3D X330 TLS: it is a three-step field method. First, the positions of the future scanning stations are roughly determined to ensure the whole recording of the building remains. Then spheres are installed visible from several stations to be able to register the project. Finally, the scans are carried out by taking care to respect a certain overlap. This overflow of information leads to an over-determined system for the resolution of the unknowns which are here the XYZ positions of the stations. Thanks to this redundancy, it is possible to obtain better results afterwards and it will be possible to discard a sphere if it presents too large deviations.

For lasergrammetry as for photogrammetry, the processing of raw data is much more complex than for point surveying. Processing was performed on the *Faro Scene* software, optimized for use with *Faro* TLS. The method being analogous for the different buildings a global presentation will be proposed.

Following the detection of targets, the import of their geo-referencing and their matching, *Scene* calculates the registration based on these targets. It seeks to optimize the location of the stations using least squares. The observation equations used are defined by the matching of the spheres. Finally, we obtain the registered point cloud corresponding to the unification and geo-referencing of the elementary clouds inherent to each station.

The aim is then to evaluate the generated results. To do so, two aspects will be addressed: a qualitative (visual) evaluation and a quantitative evaluation (supporting figures).

Qualitative analysis: Visually, on each of the different point clouds it is important to notice that the walls overlap well. In fact, there are no noticeable discrepancies and there is no lack of information. No error is noticeable on our clouds, so the quantitative analysis is to be done. The error report generated by *Faro Scene* matches our expectations with errors that do not exceed 2 cm.

Now, cleaning the point cloud of each building is needed. Indeed, it still contains elements to be removed (spheres, vegetation, noise) and needs to be sampled. The *CloudCompare* software was used for these steps. Spheres, vegetation, and noise are segmented by hand and then removed from the point cloud while building avatars are spatially sampled at 1 cm. In this way, a good compromise between an attractive visual rendering for a virtual tour and a reduced volume of data without significant loss of information was achieved. As an example, the point cloud of the forge has been reduced from almost 300 million points to about 10 million following sampling, without loss of visual quality.

Building modeling: The next step of the project consists in modeling the buildings as remain today and reconstituting their former appearance. The TLS campaign resulted in a detailed dense cloud of the foundations of the buildings. For the forge, we have an entire closed floor with five rooms and a roof. However, all these buildings had during WWII a wooden prefabricated floor above the concrete foundations. These floors were dismantled after the war and we have few pictures and thus little information today on their detailed architecture. Our purpose is therefore to assemble the different archaeological data we have, to model a version as faithfully as possible.

The methodology for the digital reconstruction of these WWII concentration camp's buildings consists in assembling the reality-based techniques (laser scanning, photogrammetry, topographic surveying) with computer aided architectural design methods, here using *Autodesk Maya*. At this stage of the project, this step is not over yet but trials on the *Autodesk Maya* software have begun. The still existing portions can be more easily modelled with the help of the dense clouds' meshing.

Indeed, we have the exact dimensions of the foundations and we can either digitize on the meshes or measure then draw directly. Drawing on *Maya* 3D modeling application, requires the use of edge loops. Using lines or polylines is not possible and all the created faces must have four or less vertices. For the missing information such as textures, upper floors' heights, roofs, windows, and doors' aspects, we refer to the archive images we have or to the archaeologists who worked on this site for a few years.

The only data we could obtain on the pictures were the number and position of the windows, doors, and chimneys, and we could also see the texture's change between the floors on the two bigger buildings (depot and forge). With a photogrammetric project using a single photo on *PhotoModeler* software, we could determine the height of the wiped-out floors. We used control points with known coordinates from the point clouds to process the photogrammetric project.

There were however a lot of information that was not available on the pictures. For example, there are faces of the buildings we cannot see so the missing data was coordinated with the archaeologists through logical reasoning and in some cases by interpretation. A colour code will be applied on the models to show the different sources of modelling with their respective levels of precision (Landes *et al.*, 2019): reliable data from the existent surveys and the pictures (such as foundations, number of windows, doors, and chimneys we can see), logical deductions from the archaeologists (buildings' texture and design of the doors, windows and chimneys for example), and total interpretation or hypothesis (missing data). The Guidi (Guidi *et al.*, 2014) methodology for the reconstruction steps, that is, modelling from simplest to most complex, from volumetric aspect to architectural details, ending with the textures was followed.

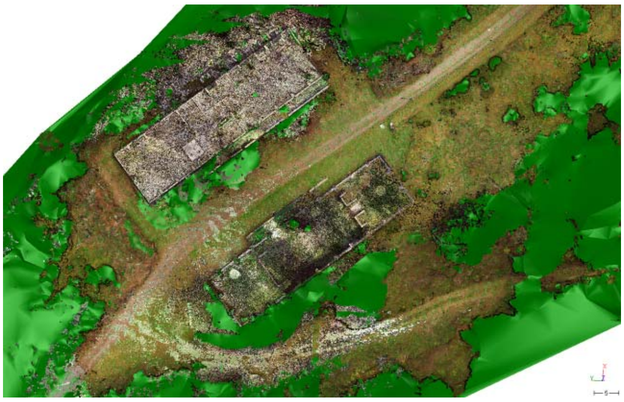

Figure 9: Extract from the DTM with integration of the point clouds of the forge and the depot.

2.3 The canteen hut

The canteen hut is in the central part of the quarry esplanade. Little information is available about the function of the building. The various plans and bibliographical sources define it as a canteen, a kitchen, an office of civil workers, or a space for technical and maintenance services (Simon *et al.* 1998; Steegmann 2005). This hut was one of the first buildings built within the quarry, when it was built at the end of 1940. The oldest photo of the construction is in the spring of 1942, but it was probably built in 1941 on the terrace with rubble and granite blocks from the pruning front. The archaeological study of the building allowed a better understanding of the construction methods as well as the function of the building. The building develops on a single level on a floor area of about 50 m^2. With a rectangular plan and a north-west/southeast orientation, it is 11 m long and 4.6 m wide. It consists of a concrete perimeter basement wall that supported the elevation of the building. The presence of a reinforced concrete mass could be related to the installation of a stove to be linked to the use of the building as a canteen or kitchen (Brangé et *al.* 2021).

Figure 10: View of the remains of the canteen hut (A. Vantillard).

2.4 The granite galleries

Three galleries are located southeast of the quarry esplanade. Despite their recurrent mention and their schematic location on several planes, their precise development has not been established until today. These galleries began to be mined by the deportees in the side of the mountain outside the fenced area in late 1943 or early 1944 and their excavation was not completed when the camp was evacuated. From September to November 1944, some deportees continued to work there while most prisoners were evacuated (Steegmann, 2005).

Contrary to what several plans suggesting, the galleries are not straight, but have important direction changes related to fracturing and natural beds of the rock. From quadrangular sections, the galleries grow over a width of about 4 m to 4.5 m, creating a large circulation space. The first two galleries, located the most westerly, develop about fifty meters in length while the last one is only about forty meters long. Archaeological observations have identified traces of tools related to the excavation of galleries. They attest to the use of the metal foil associated with the use of explosives, which were stored in two powder kegs. However, it is not possible to determine whether the perforations were made with a hand-pressed or pneumatically pressed foil (Brangé *et al.*, 2020).

The development of the galleries in a non-straight manner, their large widths and the monitoring of geological faults confirm the hypothesis that they are not galleries of exploration or exploitation of granite but spaces for the installation of an underground plant protected from air raids as was the case for example in the camp of Dora-Mittelbau (Germany, Thuringia) or in the Natzweiler annex camp in Thil (France, Meurthe-et-Moselle). The entrance to the Dora underground complex was camouflaged by a camouflage net system installed on a wooden structure at the entrance to the underground. An old photograph shows the establishment in Natzweiler of a more rudimentary similar system, consisting of wooden poles that could have been used to maintain a camouflage net.

The numerous joints, clamp collars and belts found in the galleries could also be linked to the drills or hammer-punchers used for the digging of galleries, the parts of aircraft engines or even the machine tools related to the installation of the underground factory.

2.5 Gallery modeling

There are three galleries on the Struthof site carved in the mountains by the captives with dynamite. Some traces of paint, graffities, and dynamite marks remain on the galleries walls and the archaeologists need a detailed textured model to explore these remains and understand better what happened there. The survey of underground galleries is quite tedious considering the difficult conditions of these closed cavernous environments: cold, humidity and more importantly, darkness. It turns out that TLS and photogrammetry are particularly complementary in this case. On the one hand, the terrestrial laser-scanner survey serves to capture the 3D geometry of the galleries with a high accuracy but without colouring the dense cloud because of the dark recording conditions. On the other hand, local digital photo shots with the help of spotlights capture the galleries' texture. The combination of both methods is a 3D hybrid georeferenced and textured model with a high quality.

Figure 11: Entrance to one of the galleries of the Natzweiler camp in 1945 (CERD).

Hybrid acquisition process: The acquisition process is long and uses hybrid technologies: terrestrial laser-scanner (TLS) and photogrammetry (Figure 12). First, a scanning of the entire gallery using a Faro 3D X330 TLS was carried out. Geo-referencing was achieved through classical spheres arranged along the way and visible from several scanning stations. These were surveyed by Total Station. The floor of the galleries was, especially at the entrance, covered with water and many remnants of rock scree do not necessarily allow a layout of stations according to the classical patterns.
However, because the size of the galleries are relatively small, the scanner is very efficient and provides accurate results. As the rock walls and ceiling are not smooth, on the contrary, they remained raw from explosive drilling, it was necessary to ensure many stations to avoid hidden parts and therefore holes in the surveys. The exterior of each gallery and its entrance, almost filled for one of them, was also recorded by TLS. The various rocky spurs are particularly visible. After this acquisition phase with TLS, the resulting points clouds were processed on *Faro Scene* software. Positioning significant numbers of spheres enabled registration and geo-referencing. The resulting dense cloud could not be coloured because of the difficult (or lack of) lightning inside the galleries. The three dense clouds were then sampled at a 1-mm distance and resulted in point clouds of approximately 200 million points (Table 1).
For the end use of the modeling, a resampling of the point cloud at 1-cm distance has been performed.
After the obtention of the caves' 3D geometry, the purpose was to obtain its textures through a photogrammetric campaign. The methodology applied to do so is to proceed by sides and to take up to six pictures every two meters and is related following.
The acquisition of images consisted of two distinct steps. Indeed, while lasergrammetry provides a dense and precise geometry, the images are used for texture. But to apply a well-geo-referenced texture, we used a photogrammetric survey to obtain a dense point cloud with its texture. We carried out a first survey campaign in the gallery equipped with circular barcode targets. These targets were geo-referenced using a Total Station. A first set (S1) of images was taken perpendicular to the walls with a pause time of 20 to 30 seconds at all locations where one of our 40 targets were installed. In the same series of images, we took oblique images (S2) on which several targets were visible. From a methodological point of view, we have proceeded by side. Once all the images with targets have been acquired, we have taken a third (S3) set of images, this time over the entire gallery and after removing the targets. This time we proceeded by profile, spaced 2 m. apart and including images of the walls and ceiling, preserving an overlapping of at least 60% in both directions.

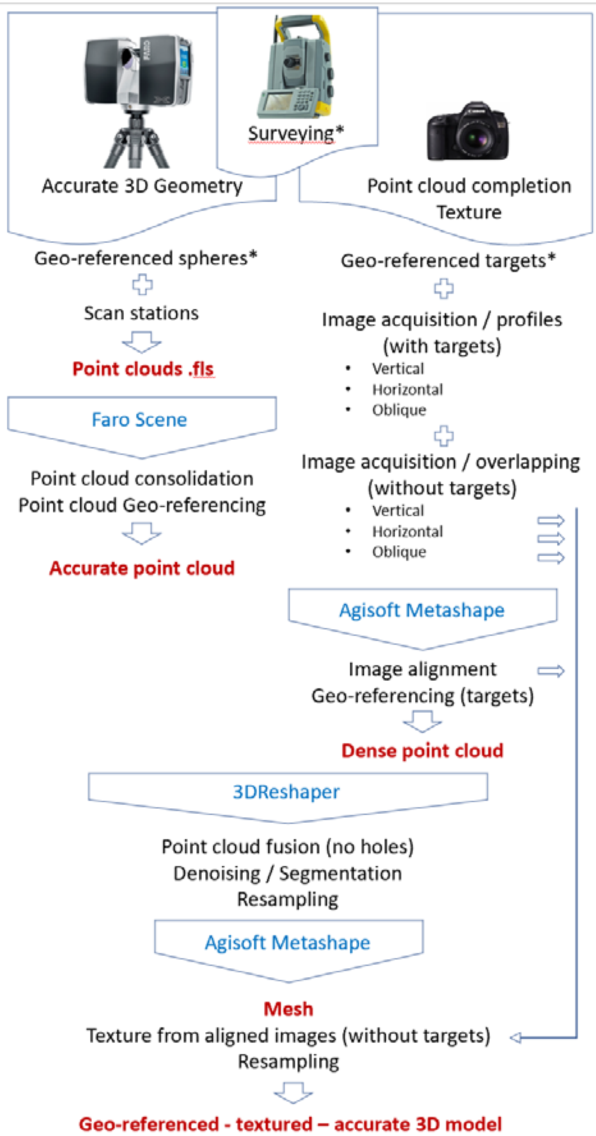

Figure 12: Modeling process using hybrid technologies.

The soil, partially water covered was not subject of a particular recording. In the last series (S3) we also added oblique images.

The acquisition of the images here was quite tricky because of the low light. We used LED plates that offer powerful but diffuse lighting to illuminate the different scenes, while trying to avoid shadows due to the raw nature of extracting the walls or ceiling of the gallery.

Galleries	#1	#2	#3
Number of points	197 M	226 M	185 M
Depth in meters	54.5	51.1	38.9
Minimum dimensions in meters (Width x Height)	2.9 x 2.5	2.6 x 1.9	2.2 x 1.0
Maximum dimensions in meters (Width x Height)	4.5 x 3.9	5.1 x 3.8	5.2 x 3.8
Overall dimensions in meters	18.62 54.46 5.61	16.74 51.11 5.56	15.08 38.89 7.06
Lowest height in meters	832.81	831.67	830.34
Highest point in meters	838.42	837.23	837.40

Table 1: Statistics of different gallery acquisitions.

The next processing step consisted of the fusion in a hybrid model of the model based on the geometry from TLS point cloud, supplemented to fill holes by extracts from the dense point cloud obtained by photogrammetry.
For processing, we used *Metashape* software to align the various photos (S3) that were geo-referenced and then consolidated with the targets detected in the S1 and S2 series, respectively.
Finally, to remove the representation of targets in the texture, we finally detached the images from the S1 and S2 series and use only the images from the S3 series to reapply the textures to the meshed model.

Figure 13: (a) Image of gallery #3 with targets, (b) Image and extract of 3D model of gallery #1.

The hybrid point cloud was then re-injected into *Metashape* meshed model, then textured with the previously obtained targetless texture model. The process has been decomposed into different chunks to optimize computational times.

The following example is given for the gallery 1. Four chunks of pictures were considered separately: the gallery's entry (about 40 pictures), its right and left side (160 pictures each), and its fundus (over 100 pictures). For both sides, we took around every 2 meters three horizontal pictures and three vertical pictures going from left to right. For the entry and the fundus, pictures have covered the area using a grid pattern method. About 40 photogrammetric targets have been placed here and there to geo-reference the work. The four chunks of pictures have been processed on *Agisoft Metashape* and the 3D textured model obtained was applied on the dense cloud.

3. CONCLUSION

Archaeological studies that have been developing since 2018 at the Natzweiler-Struthof concentration camp show what this discipline can bring to the knowledge of sites for which archives sometimes remain silent or unclear. The quarry buildings are a perfect example of this gap. There are currently a small number of contemporary photographs of the concentration period for this part of the camp (less than one third of the thirty-somethings attested for this period) (Brangé, 2020). Moreover, the testimonies of deportees assigned to the *Junkers* quarry and workshops that have reached us are very rare and not accurate. Finally, the archives related to the exploitation of the quarry, its layout and its use for the *Junkers* firm are few.
Archaeological studies conducted since 2020 allow us to better understand the organization through the various rock quarries and industrial activities that were carried out there during the concentration period. The modeling of buildings and galleries is important to the knowledge of these installations.
The 3D models provide precise documentation that can be used in scientific studies and publications. The survey of the galleries allows to better understand their functions and modes of excavation through the study of the distribution of tool traces, sneezing sites, and painted markings. These models are also a tool for proposing hypotheses for the restoration of the elevations of buildings as they were during the concentration period. In addition to the scientific aspect, they also cover a pedagogical aspect. They can be used in the context of enhancement projects (exhibitions, virtual tours and other educational tools) so that visitors to the Natzweiler-Struthof camp memorial (CERD) or Internet users can view the buildings and galleries that are currently outside the official site tour route or are inaccessible due to security concerns. The restoration of the lost elevations of the buildings will also allow a better understanding of the remains by the public.

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