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Chapter 6 Digitizing a Gigantic Nazi Construction: 3D-Mapping of Bunker Valentin in Bremen

German Summary: Dieses Kapitel präsentiert die (Zwischen-) Ergebnisse und Herausforderungen des durch das Bundesministerium für Bildung und Forschung geförderten Projektes „3D Erfassung der Gedenkstätte U-Boot Bunker Valentin durch Luft-, Boden- und Unterwasserroboter“ (Valentin3D). Das Projekt, das 2018 startete, wird von einem interdisziplinären Team der Robotics und Geschichtswissenschaften an der Jacobs University Bremen durchgeführt. Ziel ist die Erstellung eines digitalen, dreidimensionalen Modells des während des Nationalsozialismus erbauten U-Boot Bunker Valentin.

Der Bunker wurde ab 1943 im äußersten Norden Bremens unter massivem Einsatz von Zwangsarbeit errichtet. In ihm sollten nach der Fertigstellung U-Boote für die deutsche Marine nach dem Fließband-Prinzip produziert werden, in der Hoffnung, so noch eine Wende im U-Boot-Krieg in der Nordsee herbeiführen zu können. Stattdessen wurden im März 1945 die Baustelle sowie der Bunker selbst bombardiert, die Bauarbeiten im April nach erneuter Bombardierung eingestellt. Durch die Bombenabwürfe wurden auch Teile der unfertigen Decke des Gebäudes durchschlagen. Für Besucher*innen der 2015 eröffneten Gedenkstätte „Denkort Bunker Valentin“ bedeutet dies, dass für sie ein Großteil der geplanten Produktionshalle aufgrund der Gefahr von Steinschlag nicht zugängig ist. Zudem sind weitere Teile des Bunkers für Besucher*innen und auch für Forschende bislang gesperrt gewesen. Dazu gehört ein sich im östlichen Teil des Bauwerkes befindlicher gefluteter Keller, von dem die Leiter*innen des Denkortes ausgehen, dass es sich um einen ehemaligen Luftschutzkeller handelt.

Für die Erstellung des 3D Modells wurde aufgrund der Unwegsamkeit und Gefahren der weitgehend unzugänglichen Areale die Erforschung und Kartographierung mit Methoden und Werkzeugen der Robotics vorgenommen. Das Modell wird zukünftig open access verfügbar sein und damit Forscher*innen sowie Besucher*innen unabhängig von ihrem Standort Zugang zu dem Bunker gewähren. Zudem ist nun auch die Produktionshalle besser einseh- und erforschbar.

Durch die Erkundung des Kellers mithilfe eines Underwater Remote Operated Vehicles (ROV) konnten zudem neue Erkenntnisse über die (Bau-)Geschichte des Bunker Valentin gewonnen werden. Im Zusammenspiel mit zuvor nie ausgewer-

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teten Bauplänen konnte die bisherige Annahme, dass es sich hierbei, zumindest teilweise, um einen Luftschutzkeller gehandelt hat, verifiziert werden.

1 Introduction

This chapter discusses the Valentin 3D project, a collaborative work by researchers at Jacobs University Bremen and the Denkort Bunker Valentin in Bremen. It has been running since 2018 and is funded by the German Ministry for Education and Research (Bundesministerium für Bildung und Forschung, BMBF).[1] The project's main goal is the 3D-digitization of Bunker Valentin, a huge submarine pen or bunker that represents one of the most massive remnants of German World War II armaments projects. The bunker is located on the river Weser and was intended to manufacture and launch advanced submarines, with access to the North Sea via the Weser. It was built using forced labor. The war ended before the facility was completed, but the incomplete hulk is nonetheless an immense physical reminder of the Nazi period. Yet, and despite its status today as a *Denkort*, much remains to be learned about Bunker Valentin, including details of its layout and physical construction. The goal of this project is to provide a detailed three-dimensional mapping and modeling of the bunker.

This digitization project combines the efforts and expertise of both historians and computer scientists from Jacobs University with support from the *Denkort*'s management. The Valentin Bunker is a vast structure with an area of 35,375 m², with a length of 419 m, width of 67–97 m, and a height of 20–33 m. Parts of it are poorly accessible, due to structural issues and to large sections being submerged underwater. To deal with this situation, the project employs a wide range of robotic tools—including a Laser Range Finder (LRF), a Micro Aerial Vehicle (MAV) or drone, and an underwater Remote Operated Vehicle (ROV)—to survey the bunker. In this respect, the project endeavors to uncover data that would not be available without the use of specialized computerized and digital equipment. As this data is gathered, digital tools are also used to produce and process the raw data as well as models generated to researchers and other interested parties. Therefore, from start to finish, the goals of this project are to use technical means to reveal information and to make it as widely available as possible. The use of robotic tools will allow access to data that would be otherwise inaccessible,

1 The project is part of the BMBF's "eHeritage program," which aims to digitize objects of cultural significance apart from museum, library, or archive collections.

and the use of digital tools will democratize this information among researchers and the general public alike.

The focal point for this chapter is a discussion of the technical aspects of the project and its implication in the historical analysis of Bunker Valentin. This is based on our assumption that understanding the technology that produces the data is important to the historians' approach and use of this data.

The chapter's first section will introduce the bunker and its general history to give context to the project overall. In the second section, the common robotics tools used during historical explorations with the aim of digitizing cultural heritage sites will be briefly introduced; the goal is to point the reader towards literature which can be used when starting such an enterprise.

The third section will discuss the digitization processes in two different areas of the bunker and the implications of the data for historical research. Here, we first describe how the on-land ruined part was explored and digitized. The ruined part is one of the best-known parts of the bunker as it is visible to anyone who visits the site. Accessing it, however, is very difficult and in fact dangerous due to its structural instability. This inaccessibility means it has remained in its original state throughout the years, making it a very interesting area for researchers and visitors to the bunker alike. Responding to this interest, it became our main focus in the digitization. The process and equipment used for digitization of this ruined part will be detailed before discussing possible benefits of the digitization process for the *Denkort*. Subsequently, as the digitization of the ruined part is not coherent without a visualization, we will explain our approach towards the visual representation of our 3D-model. We will conclude this section with the exploration of the flooded basement under the bunker. This area has never been explored and its exact purpose is unknown. Neither were any structural details known prior to our first inspection. By analyzing the visual data gathered by the robots and comparing it to newly discovered and digitized blueprints, we can provide further evidence of the use of the bunker's basement as an air-raid shelter during its construction. Our chapter will also highlight that the digitization of the ruined part shows value especially for the *Denkort*'s educational work as the subsequent 3D-model will serve as an important tool in showing the entirety of the ruined part.

An important element of our project is its interdisciplinarity. Standing in the gigantic bunker, digitizing our surroundings, we quickly learned that we needed the expertise of both historians and roboticists to conduct our investigation fruitfully. The historians gained insights into technical possibilities and limitations of building a 3D-model. At the same time, the roboticists relied on the input of the historians while on site. We were in constant exchange about points of interest from the historical perspective and about the place's past, thus enriching each others knowledge and interests.

2 History of Bunker Valentin

Bunker Valentin is part of the National Socialist military infrastructure set up during World War II. Following Joseph Goebbels's call for "total war," Albert Speer, Germany's Minister for Armaments and Munitions, and Karl Dönitz, the navy's commander-in-chief, decided amongst other things to concentrate armaments production on submarines. Germany's naval forces had suffered heavy submarine losses in the North Sea since December 1942. In reaction to this, a new submarine had been designed, called Typ XXI. It was faster and capable of longer submersion periods than its predecessors. The production process of this new submarine needed to be protected from an increasing number of air raids by Allied Forces. Hence, in the summer of 1943, construction of Bunker Valentin started in Farge, a small village in Bremen's northernmost hinterlands.[2] The giant bunker was meant to be a safe site for the assembling of Typ XXI submarines.

A key reason for choosing Bremen as the location for the bunker was the city's existing shipbuilding industry. This meant that there was already a sufficient number of major shipyards along the Weser, which provided the necessary infrastructure to the manufacturing process. Shipyards further inland along the river, like A.G. Weser and Vulkan Werft, would build sections of the new submarines which would then be assembled at Bunker Valentin. The Ministry of Armaments and Munition decided to adopt the American assembly-line system to build the Typ XXI as it promised to reduce the construction time for a submarine from more than eleven to just two months.[3]

The building of the bunker in Farge started in May 1943. As a priority project in support of the "total war" aim, construction progressed quickly. This was aided by being provided with huge material resources as well as a giant labor force. Up to 8,000 forced laborers, from across Europe, worked uninterruptedly on the construction site seven days a week. These workers were interned in several camps located between 3 and 8 km east of the building site. These camps were not homogenous in shape, size, and internal organization. Among them

2 Marc Buggeln, "Der U-Boot-Bunker Valentin in Bremen," in *Bunker. Kriegsort, Zuflucht, Erinnerungsraum*, ed. Inge Marszolek and Marc Buggeln (Frankfurt am Main: Campus, 2008), 104–7.
3 Barbara Johr and Hartmut Roder, *Der Bunker. Ein Beispiel nationalsozialistischen Wahns, Bremen-Farge 1943–1945* (Bremen: Edition Temmen, 1989), 20.

was a satellite of the concentration camp Neuengamme in Hamburg and an *Arbeitserziehungslager* (Labor Education Camp, AEL).[4] For the forced laborers, the difference in the nature of the camps meant not only varying experiences of incarcerations but also different odds of survival; for example, the AEL was one of the deadliest of its kind in Germany.[5] Notwithstanding which camp they were interned at, the life of the forced laborers was divided between the camp, the construction site, and the journey[6] to and from the bunker, giving them little time for rest while, at times, getting minimal to no nutrition.[7]

Not all the camps were constructed exclusively for forced laborers working on the bunker. The AEL had been built in 1940 to support the armaments industry in Bremen with workers. In 1939, the Wirtschaftliche Forschungsgesellschaft mbH (Economic Research Ltd., abbreviated as Wifo[8]) contracted the Berlin-based construction company Gottlieb Tesch to build fuel depots with large tanks for the storage of various types of fuel east of Farge. Most of Tesch's workers were foreign laborers because even at the beginning of the war, Germany was already experiencing labor shortage. The laborers were forced to work for the Germans following the policy of "*Reichseinsatz*." This euphemistic National Socialist term described deployment practices during World War II, which obligated unemployed men in occupied countries to work in Germany if they failed to find work at home. Because of discriminations and rough work conditions, many

4 It is difficult to give an exact number of the camps since official records were partially destroyed and some camps were renamed or repurposed over time. Five camps can be identified with certainty; the existence of three other possible camps remains unsure. Besides the one mentioned above, more is known about Heidkamp I and II and the "Marinegemeinschaftslager" (Navy Community Camp). All three were established in connection with the construction of Valentin and not previously. Cf. further down in this section.

5 Gabriele Lotfi, *KZ der Gestapo. Arbeitserziehungslager im Dritten Reich* (Frankfurt am Main: Fischer, 2003), 193.

6 The duration of the journey would have differed between the camps. Buggeln estimates that the journey for concentration camp inmates took one hour for each route, while an inmate of the AEL remembered that his route to the construction site took around 30 minutes. It is also unclear whether camp inmates closer to the construction site would have walked, while there is evidence that concentration camp inmates were transported in open trolleys. In any case, whether 30 or 60 minutes, when working 12 hours a day, every minute not spent resting would have been an effort. Cf. Marc Buggeln, *Der U-Boot-Bunker "Valentin". Marinerüstung, Zwangsarbeit und Erinnerung* (Bremen: Edition Temmen, 2010), 78–79, 130–31.

7 Marcus Meyer and Christel Trouvé, "Denkort Bunker Valentin. Eine erste Bilanz zwei Jahre nach der Eröffnung," *Gedenkstättenrundbrief* 188 (2017): 4.

8 The name is intentionally misleading. It was a front company for the procurement, production, and storage of essential war resources, such as crude oil; Buggeln, *Der U-Boot-Bunker "Valentin,"* 12–19.

of these "foreign laborers" tried to evade work, either by performing slowly and carelessly or by absenteeism or flight. German police forces undertook various measures to fight against this so-called *Arbeitsbummelei*, amongst them the establishment of Labor Education Camps, which were supervised by the Geheime Staatspolizei (Secret State Police, the Gestapo).[9] In Bremen, the first AEL was probably built on the initiative of the Tesch company, which had complained constantly about high fluctuation and low work discipline among their Czech, Belgian, Dutch, French, and German laborers. Though primarily an instrument of repression by the Gestapo, it became a convenient means for Bremen companies to discipline their workers while still maintaining their workforce: In contrast to concentration camps, AELs were located in closer vicinity to shop floors and incarceration periods were supposed to be limited to 56 days.[10]

When construction at the bunker started in 1943, the AEL was relocated, no longer serving the Tesch company and Wifo, but now providing workers for the massive construction site. With this relocation, conditions in the AEL became extremely dire. Conditions had already been bad previously, with both beatings and the withholding of food being established actions to "discipline" and "educate" inmates; at the newly relocated camp working and living conditions became immeasurably worse, mostly due to the much harsher working conditions.[11]

In contrast to the AEL, the concentration camp in Farge was established with the purpose to provide workers to the bunker's construction site. As a satellite camp of the concentration camp Neuengamme in Hamburg, it was settled about 4 km east of the construction site in the vicinity of the village Rekum, a relatively deserted heathland. This was also the area where Tesch built some of the fuel tanks for the Wifo. Concentration camp inmates were now interned in one of the unused fuel tanks at the depot. This meant they were forced to sleep underground, hidden from view, in a circular "room" 50 m wide and 15 m high. By March 1945, one month before the Germans evacuated the camp, 2,029 inmates were living in this concentration camp. Even considering that some inmates slept in barracks above ground, this left about one square meter per person in the tank.[12] This limited sleeping space was just one of the hardships the inmates had to endure. They were also working 12-hour shifts on a diet consisting mostly of thin soup and small quantities of bread. Furthermore, inmates of the concentration camp were assigned the most dangerous and devastating work on the

9 Lotfi, *KZ der Gestapo*, 70–74.
10 Buggeln, "Der U-Boot-Bunker Valentin," 108–9.
11 Johr, *Der Bunker*, 37.
12 Buggeln, "Der U-Boot-Bunker Valentin," 111, and Johr, *Der Bunker*, 45.

construction site, for example carrying steel girders to the unsecured top of the building or 50-kilo cement bags to the concrete mixers.[13]

Further camps were established in connection with the Wifo project whose work forces were later redirected to the bunker's construction site. The Heidkamp I & II camps—established by the Organisation Todt (OT)[14]—housed Soviet prisoners of war (POWs). There were also two *Marinegemeinschaftslager* (Naval community camps), which provided housing for the guards, soldiers, and construction management who worked at the bunker.[15]

Despite the crucial role Bunker Valentin was meant to play in Germany's war effort and the number of resources poured into its construction since 1943, including the thousands of forced laborers who worked ceaselessly on the project, it was not completed by the end of the war in 1945. Although the bunker was designed to be bombproof eventually, it was inevitably more vulnerable during construction. On March 27, 1945, two British bombs punctured the bunker's roof at a spot that still lacked several layers of concrete armor. Then, three days later, American air raids destroyed most of the construction site around the bunker. However, even then, work on the bunker persisted.[16] It was only abandoned on April 7, 1945, and the camps were cleared. In fact, at this point the construction had progressed so far that the bunker was essentially complete. This is reflected in the giant structure of the building that can still be seen today. Indeed, interior construction and fitting had also been carried through, and machinery, cranes, cables, and facilities had all been largely installed; today, this is no longer apparent. However, despite its advanced stage of construction, the work had never reached the stage to see a submarine being assembled, let alone deployed, at Bunker Valentin.[17]

From 1946 to 1950, the bunker building was used as a bombing test site by the American Air Force. From 1967 on and after much debate about what to do with the massive building—options included demolition, conversion to use as a nuclear power plant, a nuclear missiles silo, and more—the Bundeswehr (German army) used it as a depot. For this, the Bundeswehr partially reconstructed

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13 Johr, *Der Bunker*, 37, 45.

14 OT was responsible for the realization of construction projects concerning armaments and protective constructions, like the Siegfried Line. It was named after its leader Fritz Todt.

15 Buggeln, *Der U-Boot-Bunker "Valentin,"* 144–54.

16 In fact, one of the recently discovered blueprints shows a plan, drawn on April 1, 1945, to repair the damage in the roof, "Vorschlag für die Ausbesserung der Decke", 01.04.1945, Bl-Nr. 2150/60aArchiv Denkort Bunker Valentin (ADBV).

17 Johr, *Der Bunker*, 21; all interiors were stripped immediately after the war either by the construction companies or villagers.

the bunker. It also denied the general public and even researchers access to the bunker, and—in a very literal sense—wiped it from the map: Hidden as a military installation, it was no longer represented on publicly available maps.[18]

Subsequently, the bunker disappeared from the public. It was only during the late 1970s that an awareness of the grim and inhuman history of the bunker and its construction began to re-emerge. This was due to a general shift in Germany's remembrance culture and the initiative of a few interested individuals. Their activities culminated in a memorial being placed just outside the military perimeter in 1983, leading in turn to a growing public interest in the bunker. Perhaps as a consequence, the Bundeswehr allowed partial public access to the site in the 1990s.[19] In 2010, Bunker Valentin passed out of the Bundeswehr's possession and the process of transitioning the entire site into a memorial officially started in 2011. The Denkort Bunker Valentin was inaugurated in November 2015 as a public memorial site which offers exhibitions about the site's past, as well as guided tours that explore the physical and historical space of Bunker Valentin.[20]

It is important to emphasize that the memorial is focused on the bunker itself. Little remains of the work camps that surrounded the site during World War II, and they are distributed too far from the actual bunker to be included in the guided tours, even though they constitute a crucial part of its history. Additionally, and as mentioned above, much of the site belonging to the memorial cannot be accessed, as areas would be too dangerous to enter or are submerged underwater. This applies especially to the ruined part, where the bombings punctured the ceiling. Given that this area of the bunker has been rarely entered in the past 75 years,[21] the ruined part has more or less retained its original state, while the rest of the building has been renovated and repurposed by the Bundeswehr. This area was intended to have housed around two-thirds of the production's operations, with many technical aspects of the assembly line. Twelve workstations were planned as part of the assembly process. In order to maneuver the submarines between those workstations, remnants of turn wheels and transport-mechanisms are still visible inside the ruined part. Also, from this part of the bunker the submarines would have been deployed into the river. Therefore, it holds a

18 Buggeln, *Der U-Boot-Bunker "Valentin,"* 168 – 85.

19 Buggeln, *Der U-Boot-Bunker "Valentin,"* 188 – 95.

20 https://www.denkort-bunker-valentin.de/startseite.html, accessed July 15, 2020.

21 A notable exception are the performances of Karl Kraus's "Die letzten Tage der Menschheit" by the Theater Bremen in six seasons from 1999 to 2005. The performances are still well remembered by Bremen citizens and, when talking about Bunker Valentin, are often associated with it. Cf. Meyer and Trouvé, "Denkort Bunker Valentin," 9.

diving basin on the northern front as well as foundations for a sluice, capable of completely flooding the bunker's northern side. Thus, even though machines installed during its construction phase were immediately dismantled after the war, the functionality of the bunker remains visible in the ruined part.[22] This is the point of departure for our digitization project, which aims at capturing these inaccessible and submerged spaces with the goal to eventually provide virtual access. In the next section, we discuss the technical aspects of this digitization.

3 Robotics for Digitization of Cultural Heritage

3.1 Remote Sensing and Geo-Survey

In the past years, *Remote Sensing* and *Geo-Survey* tools have rapidly progressed and become state-of-the-art techniques in modeling (digitizing) cultural heritage sites. One of the main reasons for their rise is that they allow for digitization of large and complex historical structures, which then can be preserved, studied, and easily shared among experts for further discussion. Furthermore, they allow accessing dangerous sites and obtaining more structural details about them. In this context, Remote Sensing and Geo-Surveying can be defined as the area of methods and processes for acquiring 2D/3D information about objects (such as cultural sites) and their perceivable properties from a distance through a wide range of sensors. The observation distance can substantially vary from very remote using satellite and aircraft data to much closer sensing with locally deployed sensors and sensor-platforms including indoor surveying.

In a typical in situ scenario, professional surveyors, including those with historical, archaeological, and technical expertise, access the target site with the needed sensors—cameras, Laser Range Finders, teleoperated robots, etc.—to collect as much data as possible. This data is then processed to extract meaningful information and representations for experts to use—maps, 3D-models, annotated images or documents, to mention just a few examples. Finally, all this heterogeneous data must be organized, integrated, and maintained through systems capable of handling massive volumes of information, also known as Big Data.

22 Marcus Meyer, "Historische Räume und forensische Pädagogik: Die Konzeption des 'Denkortes Bunker Valentin' in Bremen," in *Gedächtnisräume. Geschichtsbilder und Erinnerungskulturen in Norddeutschland*, ed. Janina Fuge, Rainer Hering, and Harald Schmid (Göttingen: v&r unipress, 2014), 357–59; for a more detailed account of the planned assembly line see also: Buggeln: *Der U-Boot-Bunker "Valentin,"* 42–43.

From the point of view of an engineer, the methods for data acquisition, aggregation, and maintenance along with their accuracy and efficiency are an evolving field. Improvements of the methods can lead to an increase in human safety and decrease in time spent during field explorations, but they also lead to better accessibility to the generated models and information from the cultural sites and objects. Recent approaches take advantage of autonomous robots to make surveys of indoor/outdoor cultural heritage sites more time-efficient and safer (the latter being a particular concern as some sites may be difficult or dangerous to access). It is also important to mention that these robots can be engineered to operate in diverse environments (land, air, and water), which offers an advantage in exploring outdoor sites.[23]

3.2 Robots and Sensors for Mapping and Surveying

Most of the work related to the documentation of cultural heritage objects relies on either Laser Range Finders (LRF) or structured light 3D sensors,[24] or photogrammetry; such and other examples are: RGB and multispectral cameras,[25] Terrestrial Laser Scanners (TLS),[26] Ground Penetrating Radar (GPR),[27] and Raman

23 Literature on the topic is mentioned in the next section. The reader can inspect the short text and video provided in Robin Murphy, *A Decade of Rescue Robots*, abstract of a paper presented on the IEEE/RSJ International Conference on Intelligent Robots and Systems, Vilamoura, Algarve, Portugal, October 7–12, 2012, accessed August 15, 2020, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6386301), for highlights of how robotic systems have contributed to exploratory missions in very challenging environments.

24 Asia Botto et al., “Applications of Laser-Induced Breakdown Spectroscopy to Cultural Heritage and Archaeology: A Critical Review,” *Journal of Analytical Atomic Spectrometry* 1 (2019), accessed August 15, 2020, doi: 10.1039/C8JA00319 J.

25 G. Guidi et al., “Image-Based 3D Capture of Cultural Heritage Artifacts: An Experimental Study about 3D Data Quality,” paper presented at the Digital Heritage International Congress 2, Granada, Spain, September 28–October 2, 2015, accessed August 18, 2020, doi: 10.1109/DigitalHeritage.2015.7419514; Susana Del Pozo et al., “Multispectral Radiometric Analysis of Façades to Detect Pathologies from Active and Passive Remote Sensing,” *Remote Sensing* 80 (2016), accessed August 20, 2020, doi: 10.3390/rs8010080.

26 Dorrit Borrmann et al., “Robotic Mapping of Cultural Heritage Sites,” *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*, suppl. W4, vol. 40, no. 5 (2015): 9–16.

27 Iván Puente et al., “NDT Documentation and Evaluation of the Roman Bridge of Lugo Using GPR and Mobile and Static LiDAR,” *Journal of Performance of Constructed Facilities* 29 (2013), accessed September 5, 2020, doi: 10.1061/(ASCE)CF.1943–5509.0000531.

Spectroscopy.[28] Due to the above discussed need to find solutions for the issues related to human safety, accessibility, and time-efficiency during surveys, hybrid sensors such as Mobile LiDAR Systems (MLS, LiDAR—Laser Imaging Detection and Ranging[29]) have been rapidly developed in recent years. At first, MLS were commonly deployed in large vehicles or backpacks; recent progress allows for MLS to be boarded in compact autonomous robots that offer more flexibility in terms of accuracy, sample density, and access to indoor and hazardous areas.[30]

Without a doubt, the design and creation of such systems have enabled a more accurate documentation of cultural sites and reduction of time and resources dedicated to the data collection phase, which normally entails finding the best position for a scan, moving the equipment to the chosen position, and making the corresponding georeferenced annotation. However, as the plethora of devices to capture data increases, effective information management systems and software are needed. For example, it is necessary to aggregate data describing a particular object provided by different sensor modalities (RGB images, spectrography, etc.) and by different levels of detail. Likewise, some of the object's representations are formed by millions of 3D points per scan, namely point clouds, which need to be stored and aggregated to create 3D-models. To achieve this, efficient mathematical methods are crucial for their visualization and dissemination among surveyors and end-users.

Based on these remarks, in the next sections we explain the technologies and methods used to digitize Bunker Valentin and to provide the processed as well as the raw data to experts and the public. In brief, for the flooded parts of the bunker, underwater robots, namely Remotely Operated Vehicles (ROVs), are used. To map the outside of the bunker, image data from Micro Aerial Vehicles (MAVs) is used to generate 3D-maps based on photogrammetry. For the inside, light conditions, absence of GPS, etc., make the use of MAVs challenging.[31]

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28 Francesco Casadio, Céline Daher, Ludovic Bellot-Gurlet, "Raman Spectroscopy of Cultural Heritage Materials: Overview of Applications and New Frontiers in Instrumentation, Sampling Modalities, and Data Processing," *Topics in Current Chemistry* 62 (2016), accessed September 5, 2020, doi: 10.1007/s41061–016–0061-z.

29 An explanation of the basic concept of LiDAR technologies is given in section 4.1.1.

30 Daniele Calisi et al., "Digitizing Indoor and Underground Cultural Heritage Sites with Robots," *Science Research and Information Technology* 6, no. 1 (2016): 23–30.

31 Heiko Bülow et al., "A Divide and Conquer Method for 3D Registration of Inhomogeneous, Partially Overlapping Scans with Fourier Mellin SOFT (FMS)," *2020 IEEE International Conference on Robotics and Automation (ICRA), Paris, France, May 31–August 31, 2020*, accessed October 7, 2020, doi: 10.1109/ICRA40945.2020.9197453.

Therefore, for this area, a 3D Laser Range Finder (LRF), concretely a FARO Focus 3D, is the canonical choice and the source of data.[32]

4 Digitization of Bunker Valentin

4.1 Digitization of the Bunker's Ruined Part

4.1.1 3D-Model Generation (Laser Range Finders—LRF)

As mentioned in the previous section (3), one of the main objectives of using robotic technologies for the digitization of cultural sites is the reduction of the quantity of resources and time used for this task, as well as the risk for human surveyors when exploring damaged or inaccessible structures. One option is to use MLS—that is, autonomous or teleoperated robots equipped with sensors. However, these systems need to be robust enough for the different types of terrain that can be encountered. In the case of Bunker Valentin, as explained previously, several areas are flooded or completely underwater (Figure 6.1) while other areas are covered in gravel from the collapsed ceiling, with some of these sections connected to underground tunnels (Figure 6.2).

This complexity in the environment demands a high level of flexibility and robustness from an MLS; for this reason and because of the poor lighting conditions and the absence of GPS, it was opted to use a LRF, specifically a FARO Focus 3D (Figure 6.3), placed manually in strategic points within the ruined part to obtain data that is processed into a 3D-model. The FARO LRF outputs a laser beam to measure the distance from the sensor to an object point by point. This distance is computed by measuring the time it takes for the laser beam to hit an object and bounce back to the sensor, namely time of flight. A rotating mirror directs the beam to scan the scene (walls, rocks, pipes) vertically in rows. The result is a text file with information about millions of points—that is, distance, vertical, and horizontal angle. A basic diagram of its functionality is shown in Figure 6.4.

Such high-end 3D LRFs provide 2.5D scans—that is, range information from the point of placement of the device, with quite accurate data over extended ranges. While it is an advantage to cover long ranges, it also creates challenges for *registration algorithms*—that is, methods used to find correspondences be-

32 These explanations cover only the basic principles of the systems' and sensors' functionality since this article focuses on their usage and synergy with historical methodologies.

Figure 6.1: Flooded turn-wheel.

tween different 2.5D scans to merge them into a single 3D-model with more details, fewer occlusions, and spanning a larger area. Note that 2.5D range data only captures the first surface hit by the sensor beam; hence, it cannot look around an object and multiple scans are needed for registration and generating a proper 3D-model. Ideally, an area or section should be covered by as few scans as possible to minimize surveying time; nevertheless, this means that the overlap between scans is also reduced, as well as the number of correspondences, which makes registration harder. Moreover, the fact that long-range scans from LRFs perform a non-uniform sampling of the environment (acquired data is denser closer to the sensor) affects the number of scans needed and their location.[33] To overcome these challenges, we developed a 3D registration method based on a spectral representation of the data, named Fourier Mellin SOFT (FMS),[34]

33 Figure 6.6 demonstrates this performance issue. It can be seen that the density of collected 3D points is less towards the edges of the scan.

34 Heiko Bülow and Andreas Birk, "Scale-Free Registrations in 3d: 7 Degrees of Freedom with Fourier-Mellin-Soft Transforms," *International Journal of Computer Vision* (IJCV) 126, no 7 (2018): 731–50.

Figure 6.2: Underground tunnel with gravel from collapsed ceiling.

and a divide-and-conquer method that checks for the best registration between several partitions of two scans.[35]

To illustrate the mentioned challenges for registration algorithms, Figure 6.5 shows a diagram with the locations of all the LRF scans made in the ruined part of the bunker. It is important to mention that more scans than necessary were taken for redundancy purposes and to further compare different registration methods, which are out of the scope of this article. The diagram shows some of the annotations used by technicians, such as the coordinate system used during the time of recording and their approximate relative position inside the bunker (the latter being approximate only as no GPS is available inside the building). The point clouds for different scan-pairs shown in Figure 6.6, in combination with Figure 6.5, show this exemplarily: If scans 35 and 37 are chosen to be registered or merged, most state-of-the-art methods would fail due to the small overlap between the scans. Scans 31 and 34 have too much overlap, which means scan 34 adds almost no new information about the environment and the time

35 H. Bülow et al., "A Divide and Conquer Method."

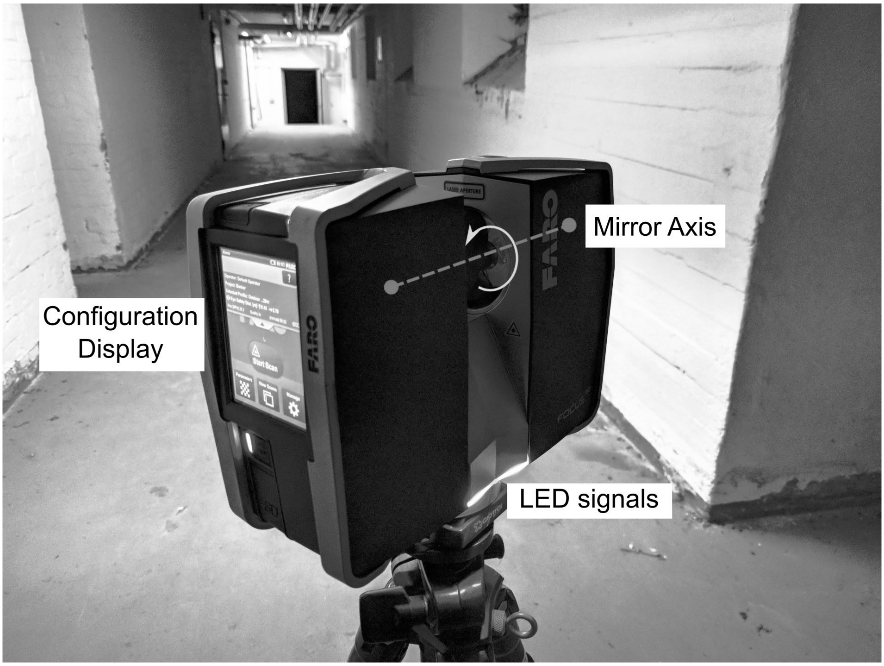

Figure 6.3: FARO Focus 3D Laser Range Finder (LRF).

invested in this recording could have been saved. The registration of scans 28 and 34 is a good example of recordings with enough overlap to have a successful registration and cover a larger area.

In the depicted scans, the millions of 3D points recorded and the aforementioned non-uniform sampling can also be appreciated. The amount of data and sampling artifacts poses significant challenges for state-of-the-art registration methods, but the Jacobs Robotics research group has developed a method based on the spectral representation of the data, Fourier Mellin SOFT, which effectively deals with these challenges. As an outcome, a 3D visualization of the ruined part of the bunker can be offered to visitors and researchers for a more detailed inspection through an interactive website.[36] Figure 6.7 shows the perspective view from the visitor's area of the ruins (access beyond this point is forbidden), and Figure 6.8 shows a snapshot of the interactive 3D-model and level

36 An official website for these visualizations has not been made yet; however, these 3D-models can be accessed through the Jacobs Robotics website: http://robotics.jacobs-university.de/projects/Valentin3D-DE, accessed July 25, 2020.

Figure 6.4: LRF scanning process diagram. Graphic by the authors.

of detail offered—that is, the far end of the hallway seen on Figure 6.7. More details about the implementation and the exploitation of the visualization for historical purposes are discussed in section 4.2.

4.1.2 Historical Dimensions

An important outcome of the bunker's digitization is the possibility it affords for the work of the *Denkort*. As previously explained, the ruined part is not accessible, but at the same time it is a big attraction to visitors, especially since it has remained in its original state. It is not feasible to renovate the ruined part and make it accessible to visitors and it is currently only visible through an opening

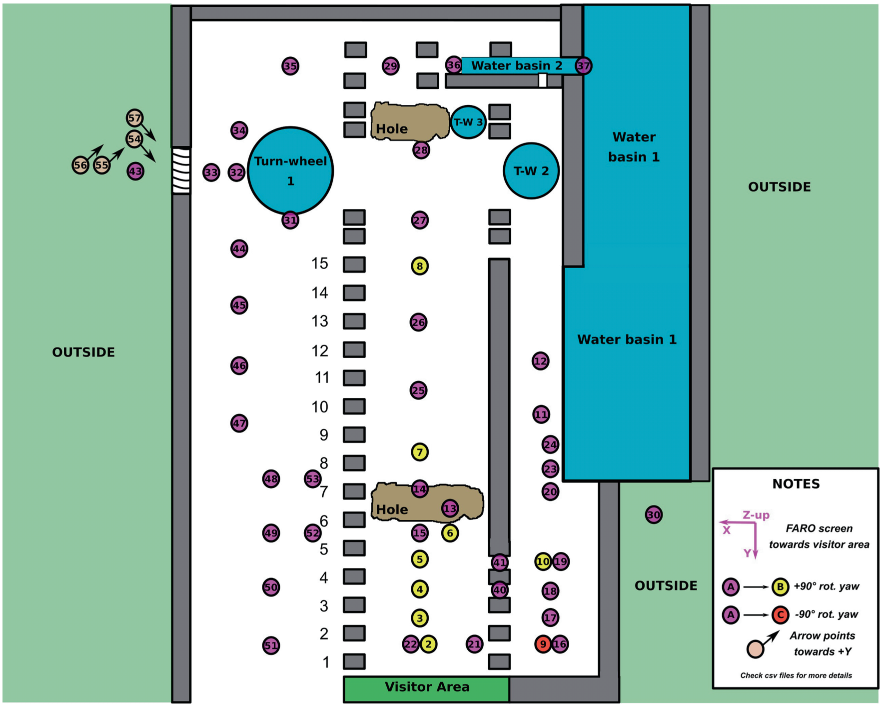

Figure 6.5: Diagram of the location and coordinate system of the LRF scans recorded in the Bunker's ruined part. Graphic by the authors.

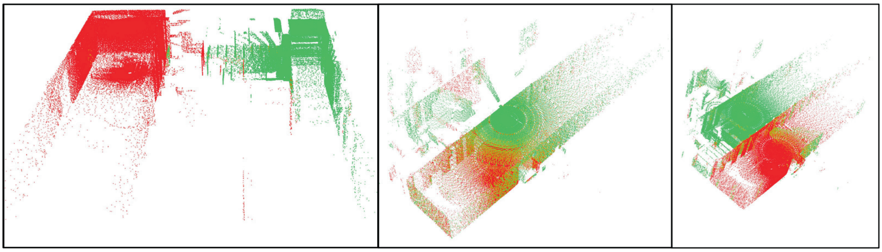

Figure 6.6: Scan-pairs point clouds: (left) Scans 35 and 37; (middle) Scans 31 and 34; (right) Scans 28 and 34.

at its far end. Hence, the *Denkort* currently has to rely on textual, explanatory notices or information provided via guided tours to describe the significance and meaning of this part of the bunker. Visitors can never fully see it, which is why myths are sometimes created. It invites rumors about hidden paths, rooms and nooks, and, more generally, secrets left by the Nazis. Or as Marcus

Figure 6.7: Ruined part as seen from visitor’s area.

Figure 6.8: Snapshot of the ruined part of the bunker in the generated 3D-model.

Meyer, historian and one of the two directors of the *Denkort* describes it: "A hall stretches out in front of the visitors, lying in semi-darkness … the end of which is barely visible from the gate and which actually has an auratic effect, i. e. characterized by individual projections and expectations."[37]

The digitization currently taking place in our project helps to deal with this issue of inaccessibility and supports the *Denkort*'s educational work, by providing it with a 3D-model with which visitors can virtually access the ruined part and better understand its history.

4.2 Interactive 3D Visualization for Research and the Public

4.2.1 Rendering 3D-Models in Web Browsers

As explained in section 4.1.1. Laser Range Finder scans produce enormous amounts of data—that is, millions to billions of points—to model 3D structures. Each of these points is represented by 3D coordinates, color values, laser energy intensity, and beam angles, etc., which means a large digital storage is needed to record them, in the order of gigabytes (GB) for each scan. This is not practical for easy visualization or sharing of the 3D-models among interested parties by (partial) download. For example, the United States Geological Survey (USGS) aims to perform through its "3D Elevation Program Initiative"[38] a nation-wide scan of the country and estimates 27 trillion points needed for its representation; this equates approximately 540 terabytes in uncompressed storage or roughly 540 laptops of average capacity available in 2020. Surveyors, archaeologists, historians, and other researchers want to access and share these data sets without copying or downloading these huge digital files. Likewise, easier access to the data will result in greater audiences; not all users will opt to upgrade their hardware or invest a lot of time to obtain and inspect the information. Taking this into consideration, one of the objectives of our project is to reach a bigger audience by making the 3D-model accessible through a web browser.

37 Meyer, "Historische Räume," 359, translated by the authors. The original German reads: "Statt dessen erstreckt sich vor den Besucherinnen und Besuchern eine im Halbdunkel liegende … Halle, deren Ende vom Tor aus kaum sichtbar ist und die tatsächlich eine auratische, also von individuellen Projektionen und Erwartungen geprägte Wirkung besitzt."

38 Larry J. Sugarbaker et al., "The 3D Elevation Program Initiative: A Call for Action," *United States Geological Survey (USGS) Circular* 1399 (2014), accessed October 6, 2020, doi:10.3133/cir1399.

With the introduction of Web Graphics Library (WebGL),[39] the distribution of 3D content over web browsers has become easier since it is natively supported by all mainstream browsers and mobile and desktop devices. However, in most cases the shared content is relatively small—that is, all data fits into memory and is rendered in real time. Terrain mapping and 3D-models of large structures, like cultural sites, usually do not fall into this category. To solve this, Potree,[40] an open-source WebGL point cloud renderer developed by the Institute of Computer Graphics and Algorithms at the Technical University Vienna, is used for our project. This software library makes use of efficient data structures and sampling techniques to select the appropriate level of detail to show to the user, depending on the 3D perspective and scale chosen to view the 3D-model. Potree is optimized to work on web browsers considering their lower data transfer rates, compared to loading data from disk, and enables several tools for inspection: area of interest clipping (clip boxes), 3D measurements, elevation profiles, and interactive annotations. Figures 6.9 and 6.10 show examples of these tools for elevation profiling and box clipping with annotations respectively.

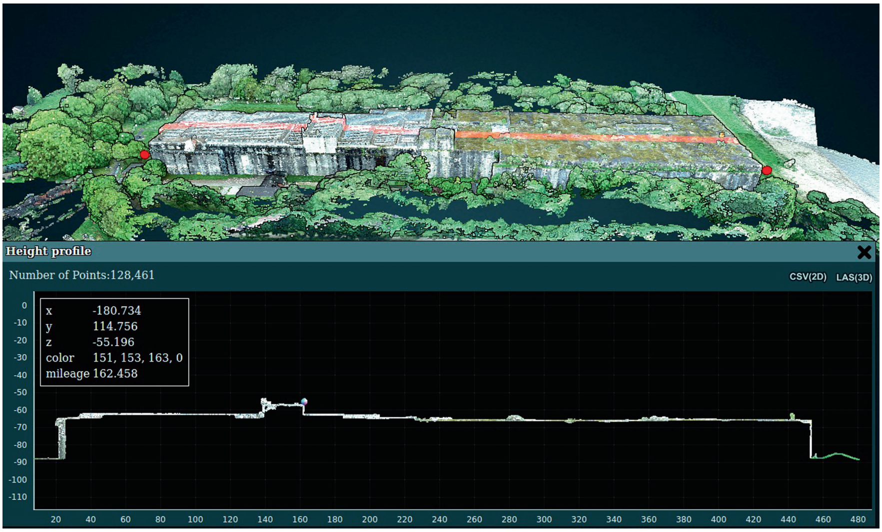

Figure 6.9: Elevation profile of the bunker.

39 https://www.khronos.org/webgl/, accessed October 6, 2020.
40 Markus Schütz, "Potree: Rendering Large Point Clouds in Web Browsers" (Diploma Thesis, Vienna University of Technology, 2016).

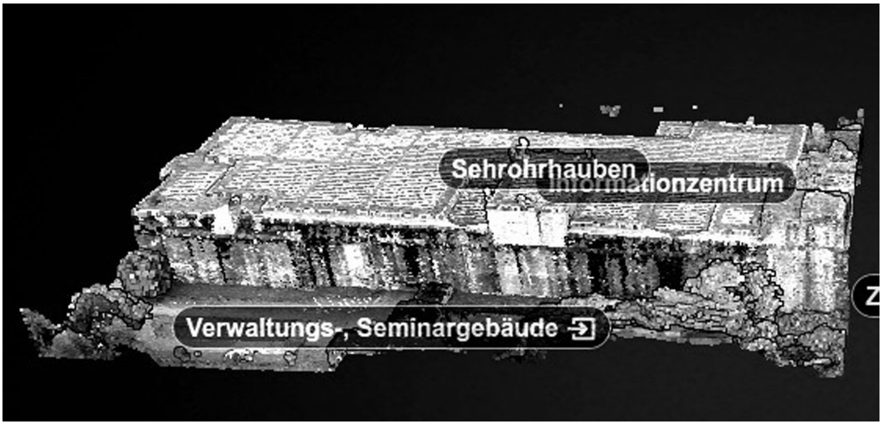

Figure 6.10: Potree visualization—interactive clipping of the 3D-model to focus on certain sections.

4.2.2 Holistic Bunker View—Exterior and Interior Models

In order to offer a more comprehensive and immersive visualization of Bunker Valentin, it was decided to also create a 3D-model of the outside and merge it with the one from the ruined part. This way, users can visualize specific sections of the bunker and inspect them, while still being able to switch to the complete view of the model for context and spatial reference. In this case, GPS can be used given that recordings can be taken outdoors. Georeferenced positions greatly simplify the registration task, as scans can be merged by simply positioning them in the 3D-model with their GPS coordinates and considering some uncertainty in these coordinates, rather than having to find visual correspondences, as is the case with the FMS method.

Even with the GPS advantage for this outdoor scenario, however, many LRF scans and significant time investment are required given that the complete perimeter of the bunker is approximately 2 km. For this reason, a MAV was used, specifically the DJI Phantom 4 Pro v2.0 shown in Figure 6.11. This MAV can be programmed to autonomously fly around the bunker and record RGB images. Most MAVs, such as the one used, do not have a laser scanner integrated. This is because it is desirable to keep their electronics and weight to a minimum. Instead, they only have a camera sensor. To generate a 3D-model from these images, which are known as photogrammetry, there are many open-source and proprietary programs available. They only require basic technical knowledge.

Figure 6.11: Micro Aerial Vehicle (MAV)—DJI Phantom 4 Pro v2.0—used to record the bunker outdoors.

For this project, Agisoft Metashape was used.[41] This and most photogrammetry software use variations of an algorithm called Structure from Motion (SfM),[42] which finds correspondences between consecutive camera images—that is, pixels from different sequential images representing the same object/scene, and computing depth information from them. In basic terms, this follows the same principle as human stereoscopic vision: when the observer moves, the observed objects move different amounts depending on their distance to the observer—for example, closer objects move more than those further away. Based on this depth and GPS position, a 3D representation of the scene can be constructed.

In Figure 6.12, the SfM 3D generated model of the bunker's exterior is shown. This model was created using approximately 900 images augmented with GPS information; the trajectory the MAV followed around the bunker is shown in blue along with some of the images taken from different locations and perspectives. These exterior and interior (Figure 6.13) 3D-models were merged using the spectral method described in section 4.1.1. Subsequently, historical annotations and images were added to finally produce the publicly available web browser Potree version.[43]

Potree presents different options for annotations that are especially useful and interesting for historians. Besides allowing simple text annotations, differ-

41 https://www.agisoft.com/buy/licensing-options/, accessed October 8, 2020.
42 Jonathan L. Carrivick, Mark W. Smith, and Duncan J. Quincey, *Structure from Motion in the Geosciences* (Chichester, UK: Wiley-Blackwell, 2016).
43 See for the exterior: http://robotics.jacobs-university.de/datasets/Valentin3D/3Dmodels/birdeye-exterior/visualization.html, and the interior: http://robotics.jacobs-university.de/datasets/Valentin3D/3Dmodels/ruins-interior/visualization.html, both accessed October 12, 2020.

ent media can be inserted, ranging from weblinks to photographs and videos. These annotations thus make historical contextualization possible. For example, a structure currently existing could be compared against previous versions and different states at a given point in time. For our project this means that the functionalities of each bunker section, especially the ruined part, can be conveyed—something that is not possible in the analog world, as discussed above. An annotated model can thus help to demystify water filled hollows and dark nooks or corners and their planned purpose can be shown. What is more, the bunker's violent past can be made visible by inserting pictures from forced laborers during the construction phase. In the model, these can be linked to the corresponding parts of the bunker on which they worked. When implemented into the *Denkort*, with these methods the public will be able to look holistically at and into the bunker not just in its current state but also at the violence that was the basis of its construction.

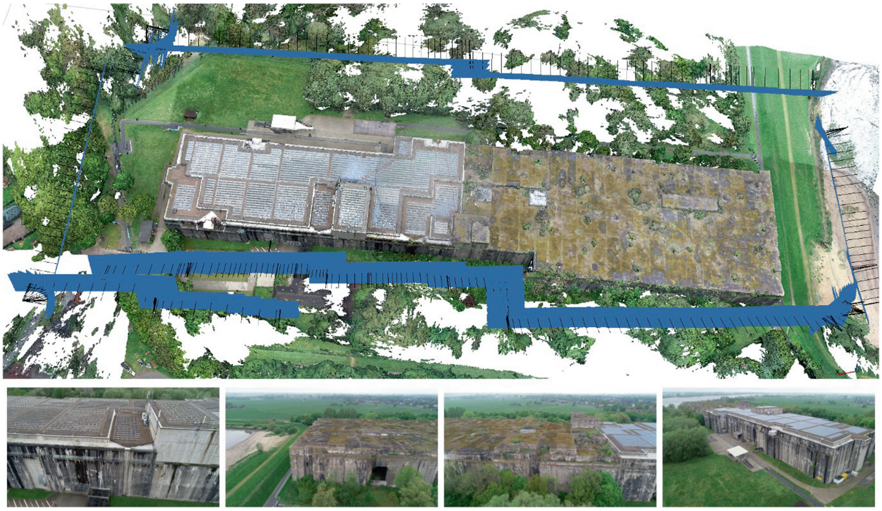

Figure 6.12: (Top) Structure from Motion (SfM) 3D-model generated with (below) camera images taken with the Micro Aerial Vehicle (MAV) while flying around the bunker, its trajectory is shown in blue.

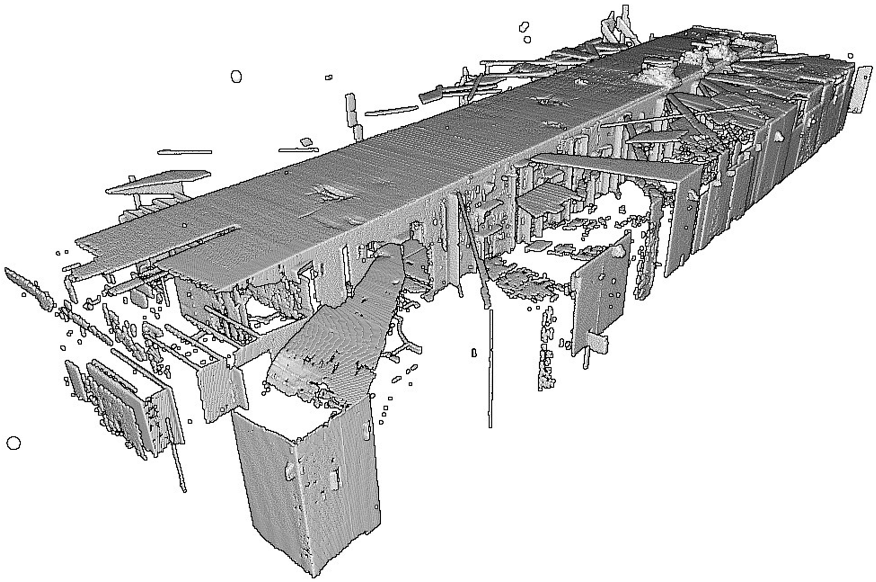

Figure 6.13: 3D-model of the indoor ruined part of the bunker (grayscale version) generated with the Fourier Mellin SOFT (FMS) registration method.

4.3 Bunker Basement

4.3.1 Historical Dimensions

In addition to the ruined part, the most eastern section of the bunker is also inaccessible to the public. The reason for this, however, is different than for the western side. This eastern part of Bunker Valentin is not part of today's exhibition offered by the *Denkort*, as it is still used by the owner of the building, the Bundesanstalt für Immobilienaufgaben (Institute for Federal Real Estate, BImA). In the historical layout planned for the bunker during World War II, this eastern area would have been divided into at least two floors and would have mostly held manufacturing workshops. Recently discovered blueprints, now kept in the *Denkort* and partially digitized as part of our project, show how diverse these workshops would have been. For example, it was planned that on the ground floor a shipbuilder would have been housed, as well as a machine workshop and a toolmaker with a forge. A paramedic's office would have been found here as well.[44] On the second floor, a pipe maker, carpenter, and locksmith were supposed to settle. However, this floor was also meant to hold the offices of two electrical companies, Afa and AEG. It can be assumed that these two companies would have been responsible for manufacturing and installing the submarines' vital lead acid batteries.[45]

The floor plans show the diversity and complexity of the work involved in completing the submarines. The fact that these workshops would also have created new jobs could have been an argument of the National Socialist government to make the massive construction more acceptable to local residents.[46]

Overall, in the most eastern section of the bunker, our project focused most on its basement. Due to its constant flooding, it has been barely explored in the past. There is only one discernible entrance to the basement, a staircase close to the eastern outside wall of the bunker. It is narrow and badly illuminated, as can be seen in Figure 6.14. There has been no assessment about the structural integrity of this part of the bunker. For these reasons, human (diving) explorations have been impossible.

Based on witness reports, the executives of the *Denkort* believe it to be an air-raid basement, used during World War II by nearby residents of the village of Farge and managing staff from the construction site.[47] The only other source of information about this bunker's section is recently discovered blueprints. This makes a precise structural and historical description of the basement difficult. Our project, for the first time in probably decades, made a closer exploration of the basement possible, with the goal to answer the question of its purpose.

For the exploration of the basement, a different approach was adopted than that used for the ruined part. Instead of using robotics tools to augment and merge already existing data about this site—from sensors and construction plans—semi-autonomous robots performed exploratory missions supervised by the project's historian. The goal was to pinpoint possible objects or areas of interest from the video footage. This exploration in conjunction with consulting the blueprints supported the assumption that the basement was used as an air-raid

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44 "Bauvorhaben-Valentin. Einrichtungsplan Erdgeschoß," 9.02.1944, Bl.-Nr. 80a, ADBV.

45 "Bauvorhaben-Valentin. Einrichtungslager – Obergeschoß," 09.02–13.03.1944, Bl-Nr. 81a, ADBV.

46 On the relationship of local residents of Farge, the bunker, and the forced laborers see Buggeln, *Der U-Boot-Bunker "Valentin,"* 155–59 and especially Silke Betscher, "Der Bunker und das Dorf," in Marszolek and Buggeln, *Bunker*, 121–36.

47 Forced laborers would most likely have been denied entrance to the bomb shelter.

shelter during World War II. In the following, we will first discuss the technical aspects of this exploration and afterwards detail the resulting historical findings.

Figure 6.14: Only known entrance to the basement in the eastern section of the bunker. Images show the poor illumination conditions, narrow access, and level of flooding in the basement, as well as the Remote Operating Vehicle (ROV) used for exploration.

4.3.2 Underwater Remote Operated Vehicles for Historical Surveys

The Remote Operated Vehicle (ROV) used for this task is a VideoRay Pro 4.[48] This ROV is a 37.5 × 28.9 × 22.3 cm and 6.1 kg underwater robot that can be submerged to approximately 300 m; it is attached to a control box with a 40 m tether. The tether not only allows command over the direction and speed of the ROV via joystick, but also the reception of video footage from the integrated camera (640 × 480 pixels) in real time. In this way, the technical operators and historians can cooperate during survey missions to investigate points of interest, which are described later in the text. However, we first discuss some of the challenges that are commonly encountered while performing underwater surveys.

48 https://www.videoray.com/rovs/videoray-pro-4.html#!_SRC1370_sm, last accessed October 10, 2020.

An underwater scenario poses in general a more difficult task than its counterpart on land, as a GPS signal cannot travel underwater and the human operator may not always have a direct view of the robot used for exploration. There are several methods for obtaining an approximate underwater localization; one of the most common is to have another vehicle or station on the surface, which communicates acoustically with the ROV to know its relative position, then the station on the surface can access GPS data and provide a global position for the ROV. Another way is to deploy an infrastructure of sensors underwater on fixed and known locations beforehand with which, again, the position of the ROV can be calculated based on the acoustic transmissions between all these sensors as shown in Figure 6.15.

However, in our project, the narrow and already submerged entrance to the basement does not allow for the fixing of a surface station. Additionally, as diving is so dangerous as to be effectively impossible, no acoustic infrastructure can be deployed in advance. Furthermore, confined spaces with concrete walls make acoustic underwater localization almost impossible due to echoes and the related multipath and interference effects. Thus, a very rough localization is made heuristically by the operator based on landmarks and compass measurements from the ROV, and no accurate 3D mapping is possible under these conditions.

Likewise, the layout of the basement presents a scenario with more physical obstacles (including rubble, walls, pipes, etc.) than the typical open-sea or lake environment where the ROVs are usually used. Hence, the operator needs to be careful not to tangle the tether in such a way that it can be broken, leaving the ROV irretrievable. This makes the survey missions time consuming since the ROV needs to be maneuvered carefully and thus slowly in these surroundings. The final important challenge is underwater visibility. Visibility was highly variable because of the sediment particles floating in the water as shown in Figure 6.16. The number of particles obscuring vision was mostly dependent on the ROV's distance to the particle-covered surfaces and the thrust of its propellers. These particles reflect the light used by the ROV causing what is known as light backscatter, diffusing the light, making the images blurry and attenuating colors. As mentioned, to surmount this challenge, very slow speeds were used when controlling the ROV and manual annotations about landmarks were made to gain a very rough 3D estimate based on knowledge of the blueprints.

After a couple of rehearsal missions to acquire experience operating through the basement while keeping the equipment safe and adjusting the lights and camera for better visibility, several surveys were made and objects of interest were annotated. These will be discussed in the following sections.

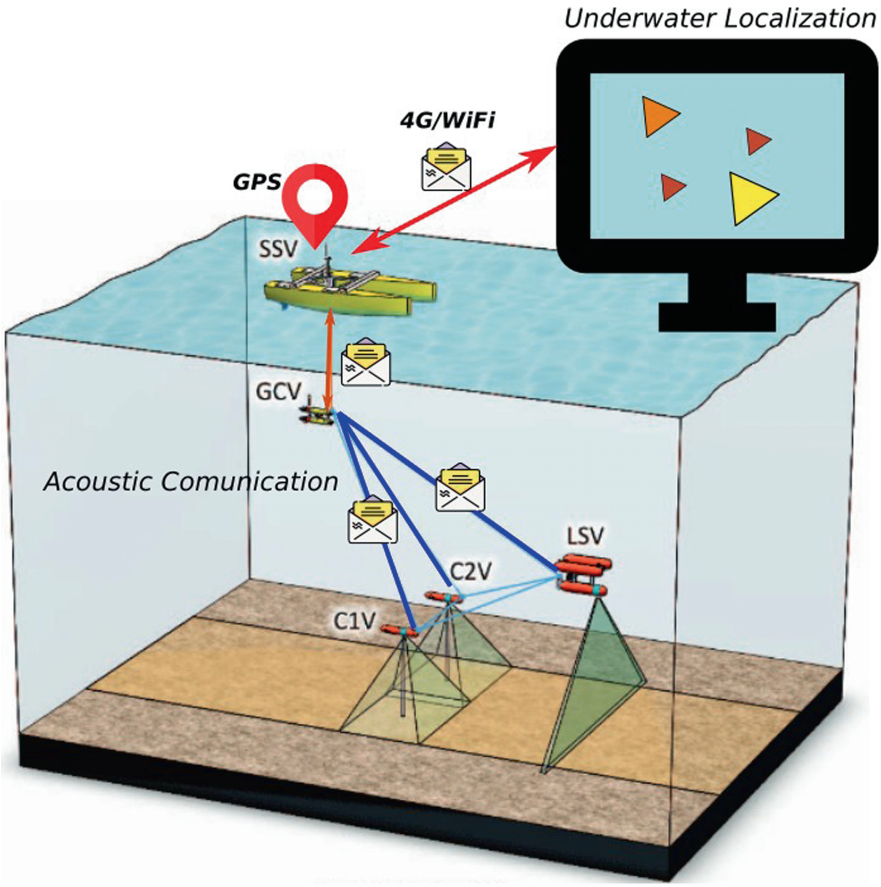

Figure 6.15: Common sensor/robotic setup to achieve accurate localization underwater. A surface vehicle has access to GPS or wireless localization, which is propagated to the underwater vehicles through acoustics. Graphic by the authors.

4.3.3 Survey and Historical Findings

The exploration of this space revealed a sizable room whose floor is in large parts scattered with rubble. The rubble is difficult to further identify because of a constant layer of algae or some other form of particles in the water; it seems to consist mostly of unidentifiable stony objects and some bricks. Furthermore, we discovered a brick wall. This was surprising, since all other wall structures are made of concrete. Given this context, this wall seems to be out of place. The most unexpected finding, however, was a circular construction with a rim

Figure 6.16: (Left) view of the Remote Operating Vehicle exploring a water basin with clear water; (right) example of sediment particles hindering camera vision through light back-scatter.

rising from the floor located close by this brick wall. The outside of the rim looks like it is made from stone. A pipe seems to come from the ceiling and hover over the middle of the well. In Figure 6.17 these parts of the basement are depicted.

Comparing the ROV's images with the blueprints allowed us to identify this structure as a well (the German word *Brunnen* is used on the blueprint). As can be seen in blueprint 2440/2d, which shows a lateral cut through the base plate, this well leads from the basement to the ground floor. It is also visible in a floor plan that shows parts of the workshop section.[49] The floor plan further reveals that recesses would have led from the well through parts of the workshop, partially ending in a rectangular deepening. Consultation of the facility's blueprints of the workshop's ground floor show that sanitary facilities were planned on the spot of the deepening.[50] Based on this, it can be discerned that the well would have been part of a sewage system.

During the initial exploration of the basement, and without consulting the blueprints, we assumed the well must be connected to the flooding of the cellar and should in some ways have ensured avoidance of the influence of groundwater. The close proximity to the river Weser in combination with its significant tide[51] makes it likely that groundwater being pushed from the river's tide into the building would be a serious issue not only during construction but also later. This could explain the current flooding of the basement. In accordance with this theory, the blueprints show that several pump stations were planned, especially in the eastern part of the bunker. For example, blueprint 2440/41a

49 "Sohlplatte. Schalplan über LU-Keller Nord," 31.5.–14.7.1944, Bl. 2440/2d, ADBV.

50 "Einrichtungsplan Erdgeschoß," 9.2.1944, ADBV.

51 In Farge the river drops and rises more than 3.5 meters per tide: http://www.pegelonline.wsv.de/gast/stammdaten?pegelnr=4950020, accessed October 25, 2020.

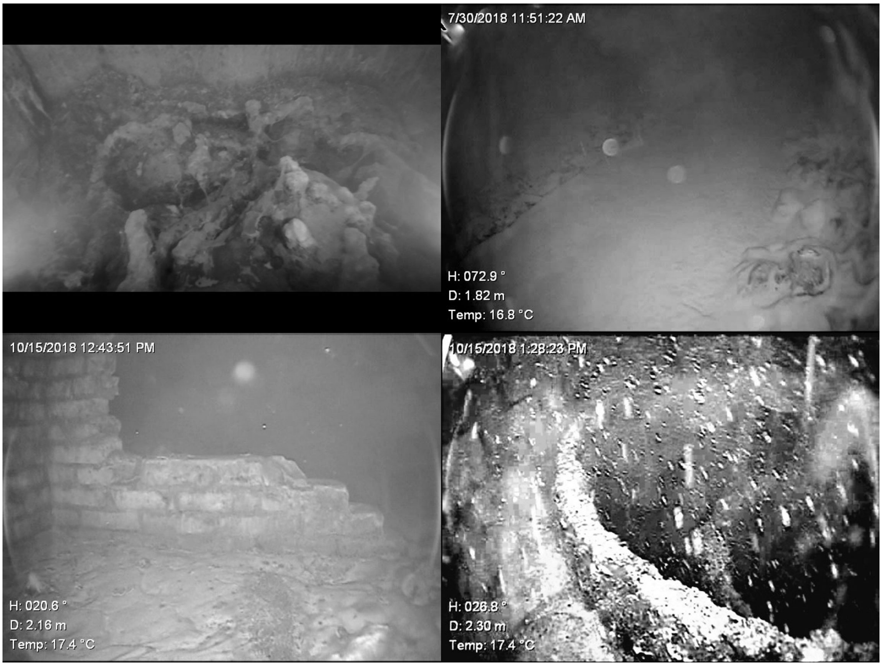

Figure 6.17: (Top left) rubble with layer of algae; (top right) clear path with rubble on the side, suspected of being human-made before flooding; (bottom left) brick wall apparently not in the blueprints; (bottom right) well with stone rim which apparently was connected to the floor above through a pipe.

shows a sump basin (*Pumpensumpf*) with a drainage pipe close to the north-eastern gate. This construction plan also refers to another blueprint for details; 2240/38 shows a staircase leading into an air-raid basement ("Lutzkeller Süd," abbreviation for the German term for air-raid basement, *Luftschutzkeller*). Adjacent to the staircase, a room was planned in which the floor slopes around 1% towards the staircase.[52] At the end of the slope, again, a sump basin can be found in the blueprints. Sump basins can also be seen on the construction plans for the turn wheels in the western part of the bunker.[53] All this suggests the bunker has a larger issue with water, most likely ground water. It could explain today's flooding of the basement as well as that of the southern turn-wheel

52 "Schalplan für Sohlplatten SI bis SV," 10.8.1944 – 17.8.1944, 2440/38b, ADBV and "Sohlplatte SVI bis IX. Schalungsplan," 21.8.1944 – 28.8.1944, 2440/41a, ADBV.
53 "Schalplan für die Sohlplatte S XV," 13.12.1944 – 3.1.1945, 2440/112a, ADBV and "unbekannt" [Schalplan für Sohlplatte Drehscheibe bei VI/1], n.d., ADBV.

in the ruined part, as depicted in Figure 6.1. It can be assumed that the phenomenon of rising water also needed to be managed during construction of Bunker Valentin and for the planned assembly of submarines.

As briefly mentioned, blueprint 2240/38 shows the entrance towards "Lutzkeller Süd." This is complemented by another construction plan, describing parts of another air-raid basement referred to as "Lu-Keller-Nord" (abbr. for *Luftschutzkeller-Nord*, as in "air-raid basement north").[54] As both plans show entries of the air-raid-basement towards the same part of the bunker, it is safe to assume that the shelter had two entrances, although they would have been at the beginning of the workshop section rather than its end, where there is a staircase into the basement today. Furthermore, the blueprints indicate that access to the air-raid shelter would not have been permanent. They include a note that advises to close at least the northern entry later in the construction process. This would make sense, insofar as further bomb shelters inside the bunker would have been superfluous once construction was completed, because as a whole it should have been impenetrable to bombs.

Thus, in sum, by evaluating all digital material from the ROV in combination with the blueprints we can verify the assumption that at least some parts of the basement were used as air-raid shelters. In fact, our research shows it was indeed planned exactly for that purpose.

Further inquiry is needed to determine just how exactly the rubble on the floor of the basement got there. It would not have been feasible for an air-raid shelter to have items on the floor, as these would have been hurdles or obstacles where a free path is strictly necessary to ensure accessibility, especially for people in panic. The most likely scenario is that the basement was used as a dumping ground during renovations by the Bundeswehr after the war. However, it remains an open question why the basement, and not a more accessible area was chosen for this purpose. In any case, the rubble must have been put in the basement while it was not flooded, since the rocks are evenly distributed and "pathways," clear of any rubble, are distinctly discernible.[55]

Further investigations into the basement itself are also necessary. More field explorations need to be done to conclusively confirm that the basement explored so far is accurately displayed on the blueprints showing the north and south air-raid shelters. Our project's explorations came to a halt due to the Covid-19 pandemic, and are now only slowly progressing.

54 "Sohlplatte. Schalplan über LU-Keller Nord," 31.5.1944–14.7.1944, 2440/2d, ADBV.

55 As can be seen in Figure 6.17, top right.

The blueprints themselves also need to be further examined, which should at least be partially done in cooperation with an architect to ensure architectural specifics in the plans are understood. There are several reasons, though, why further examination will prove complicated. The quality of the sources in combination with their size make it difficult, if not impossible, to move them without damaging them further. As is usual with construction plans, the paper is very thin and fragile, and the biggest blueprint comes to a size of approximately 200 × 100 cm. Handling and storage of the plans so far has already left marks to such an extent that some blueprints are barely usable anymore. To minimize further handling and damages, the sources are being digitized. Until now, we have reviewed, photographed, and cataloged half of the blueprints (around 230). It is important to mention that the photographs are very rudimentary[56] and most likely will not serve as a substitute for professional digitization, such as scans, at least for the most important and interesting blueprints. We are currently looking into effective digitization strategies that consider both the size and fragility of the sources.

5 Conclusion and Outlook

The three-dimensional mapping of Bunker Valentin is a challenging endeavor from which the historical research community will benefit. Digitization and the mapping resulting from our project mean that the bunker and in particular its inaccessible ruined part can soon be visited and researched remotely from every point of the globe. Especially for spatial and architectural research, our 3D-model offers features that simplify analyses. For example, measurements can be easily and accurately performed within the 3D-model. In real life, this would be extremely complex and time consuming because of the bunker's large dimensions and accessibility constraints. Simple visualization and access to the 3D-model was not initially a priority of the project. However, the research team quickly realized the importance of organizing the massive amount of data obtained, and of providing an easy way to interact and share the data with the public and researchers. The visualization is still work in-progress and it will be improved with feedback from the community. Furthermore, since the raw data will be partially available through open access upon request, it can be manipulated to serve and assist historical research. Researchers can organize and analyze the source data depending on their needs and methodologies.

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56 Which is also why we refrained from printing them in this chapter.

Our current 3D-model will be augmented with historical annotations, images, and digitized blueprints—that is, with traditional sources. This will be done to provide a coherent source for historical research. When the integration of 3D scans and other material is complete, the achieved results will help to further clarify the history of the ruined part. Furthermore, our project will contribute to make the bunker's functionality more visible and understandable. It will therefore also serve as an aid to the *Denkort*'s aim to convey the history of the bunker as holistically as possible.

After extensive inspection and cataloging of the blueprints in combination with the visual references, several parts of the bunker were analyzed. This allowed us to confirm that the basement was at least in part planned and used as an air-raid shelter.

In this chapter we have shown that historical research benefits from the synergy between traditional historical sources and state-of-the-art robotics tools. The exploration of the basement shows how historical research can be supported by Remotely Operated Vehicles. In our project, it led to this bunker section being explored for the first time in decades. However, without the original blueprints as sources and points of reference, our findings could not have been reached. In other words, while the exploration would not have been possible without technical aid, the historical research question could only be examined fruitfully by connecting digital exploration with the reading of "traditional" material.

But it is important to emphasize that more is needed than a synergy between information sources or tools. Additionally, a collaboration between different scientific communities—history and engineering—is required to advance the exploration and understanding of cultural sites. This is not trivial: Often historians cannot keep track with the fast-paced technological advancements used for surveying, while engineers do not know how to best portray the obtained information so that it can be of use for other disciplines.

From the technical perspective, it became clear that structures such as Bunker Valentin can be very complex to survey as they consist of several different environments: almost inaccessible sections, underwater parts, highly variable illumination, etc. It is not enough to have one precise tool for exploration but a collection of them is needed, so that anyone can easily adapt to these different scenarios and crosscheck the acquired information. Ideally the next step would be to assemble multi-robot teams performing surveys in parallel in the different parts of the bunker while reporting back to a central system. This could make these exploration endeavors highly efficient and reduce the efforts in aggregating the information from all these different sources. Nonetheless, as explained previously, such enterprises must have the supervision and guidance of historians, who point to relevant places, so as not to blindly collect massive amounts of data that could be cumbersome to filter and would not be required for answering historical research questions.

In the future, such synergies should be used to work on the less explored areas of the bunker's past. More precisely, further interdisciplinary projects should target the area which housed the camps where forced laborers working on the bunker were detained. Even though this area constitutes a key component of the bunker's history, some camps have been researched only rudimentarily. Since the locations of the former camps, starting 3 km east of the bunker extend over an area of 5 km, it is difficult for the *Denkort* to integrate this area into their guided tours. Furthermore, access is difficult as parts of the terrain are used today as a military exercising site by the Bundeswehr and also cross the federal borders between Bremen and Lower Saxony. All these aspects were also why the digitization of the former camps was not within the scope of our project. However, this limitation should be overcome in a future project. A digitization of this area, concentrating on the former camps, would create a virtual access opportunity benefiting both researchers and visitors to the *Denkort* interested in the history of Bunker Valentin and the Nazi period in Bremen.

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