

A Multi-Level and Multi-Sensor Documentation Approach of the Treblinka Extermination and Labour Camps

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Abstract

At Treblinka extermination camp, almost one million of people were killed during the Holocaust. A further 10,000 people are estimated to have been murdered at the nearby labour camp. Since 2007, the Centre of Archaeology of Staffordshire University (UK) has been involved in the study and research of the evidence of these atrocities in order to demonstrate how an archaeological approach to Treblinka has, and will continue to, enhance contemporary discussions about the camps and provide a richer, more accurate record of events. This study focuses on the use of digital 3D technologies and web visualization tools for the analysis of the sites, providing a digital interactive platform which can be used both by professional users and a public audience. It proposes a pyramidal multi-level and multi-sensor approach - providing a 3D resolution spanning from a few centimetres in the landscape Digital Terrain Model to few millimetres in the layer-by-layer archaeological test trench (Figure 1).

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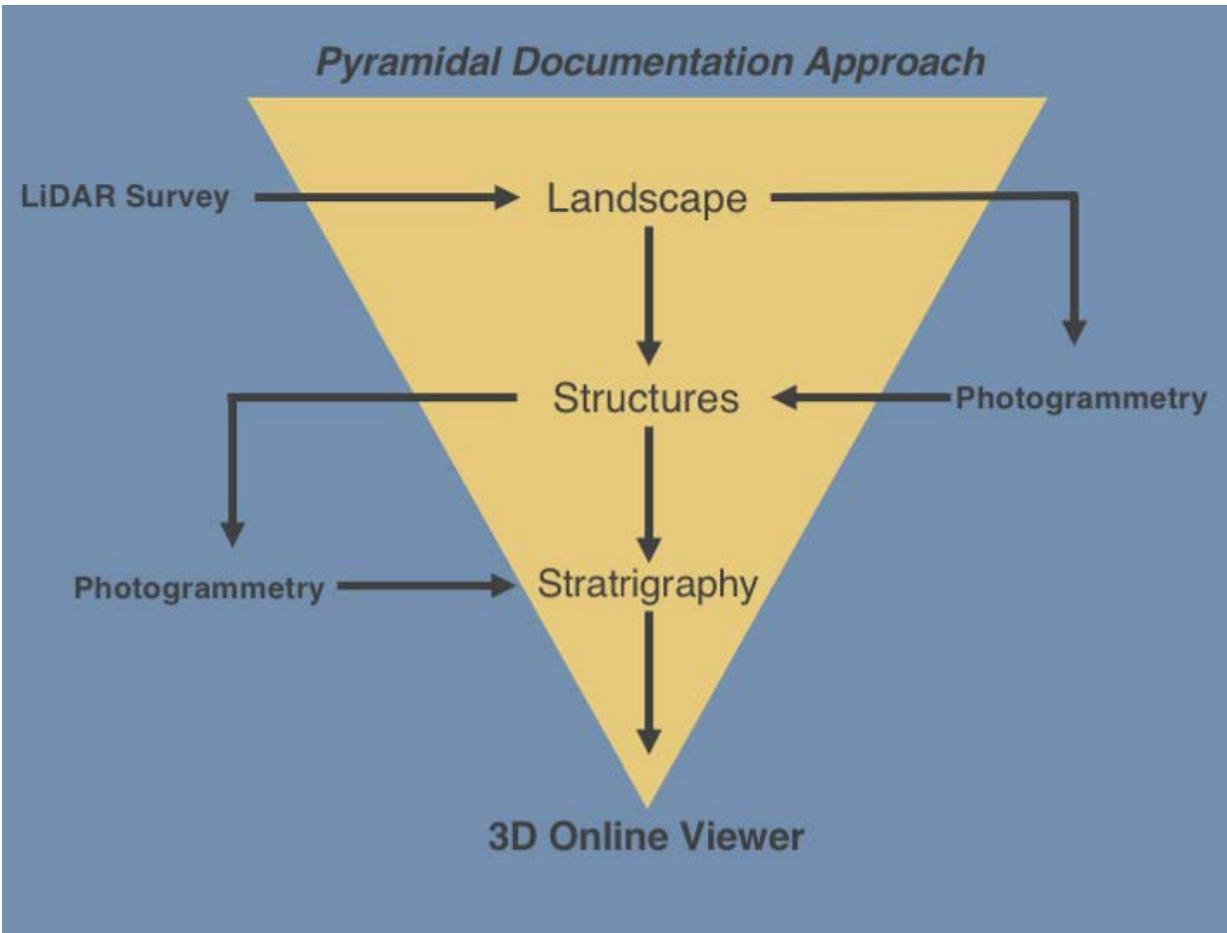


Figure 1. Graphical Abstract

1. Introduction

In 1942, an extermination camp (Treblinka II) was constructed close to Treblinka railway station, in a remote area of forest, north-east of Warsaw, Poland. This camp was built as part of Operation Reinhard; an operation developed by the Nazi party to eradicate the Jewish population of Europe [1]. From when it received its first transport on the 23rd July 1942 until the autumn of 1943, the camp at Treblinka allowed the Nazis to murder between 800,000 and one million people [2]. These victims were mostly Jews, but Roma, Sinti and Polish non-Jews were also killed.

When the camp closed, it was demolished and the landscape today (a memorial site) reveals little of the former geography of the site. Visitors to Treblinka are unable to view former camp structures

or their locations, and little information is provided about the events that occurred. The extermination camp was built close to an existing labour camp (Treblinka I), constructed in 1941, where it is estimated that a further 10,000 people were killed. This camp housed Polish political prisoners, Jews and Roma until May 1944 [3] (Figure 2).



Figure 2. Treblinka Extermination Camp (Left) and Labour Camp (Right)

This study reports on a multi-resolution and multi-sensor approach developed by the Centre of Archaeology of Staffordshire University (UK) for the accurate and detailed 3D documentation of the archaeological structures and remains of Treblinka I and II. Data capture has been planned according to a top-down strategy aiming to achieve a resolution spanning from a few centimetres down to few millimetres. All the information has been then integrated in a single open-source web visualization tool intended both for professional use in the field of archaeological science and for use by a wider public audience.

2. Related Works

The documentation of structures and excavation is today a standard practice in archaeology. A multi-resolution approach and the integration of different modelling technologies and methodologies can provide the best results for integrating landscape, structures, stratigraphic

excavation and finds [4]. Indeed, different projects have highlighted the potential of image- and range-based modelling in the heritage sector. In Gruen et al. [5], a multi-resolution approach exploiting passive sensors is presented for the documentation of the valley of Bamiyan where the giant statues of Buddhas existed before they were destroyed by the Taliban in 2001. A GIS database has been realized for the UNESCO area. A 3D multi-resolution approach was applied at the Rucellai's chapel in Florence [6]. The authors present a new complete survey aimed to support restoration tasks. El-Hakim et al. [7] integrated drawings, images and range data for the modelling of castles and their landscapes. Starting from the extrusion of massive models from 2D plans, the architecture could be studied and areas requiring more accurate modelling could be defined.

A multi-resolution and multi-sensor approach has been developed by Guidi et al. [8, 9] for the accurate and detailed 3D modelling of the entire Roman Forum in Pompei in Italy. Active and passive sensors were used for the digital documentation of the archaeological site trying to fulfil all the surveying and archaeological needs and exploit all the intrinsic potentialities of the actual 3D modelling techniques.

Remondino et al. [10] presented a reality-based project, exploiting multi-resolution and multi-source documentation for the digital reconstruction of a part Maya archaeological site of Copán, Honduras. The final goals were to provide digital 3D models for research and public education purposes.

In Cantoro [11], a 3D approach is proposed for the integration of aerial and terrestrial data accessible through a web-based platform.

3. A brief history of Treblinka I and II camps.

As noted above, the Nazis began transporting people to Treblinka extermination camp (Treblinka II) in July 1942 and, by the autumn of 1943, 800,000 to one million people had been killed there

[1]. Along with Belzec and Sobibor, Treblinka was intended to be an efficient killing centre; hence, people were usually murdered immediately upon their arrival. Most of the victims were killed in gas chambers by carbon monoxide gas poisoning but some were shot. Their bodies were buried in mass graves and later they were cremated [2]. Because of the speed of the killing process, living accommodation only existed for the SS guards and for a few Jewish prisoners who were forced to help clean up after the murders took place. Before this camp was built, Treblinka housed a labour camp (Treblinka I), where it is estimated that a further 10,000 people perished as a result of the Nazi 'death through work' policy and executions between autumn 1941 and spring 1944 [3].

Although the history of the extermination camp is fairly well known, the labour camp has been documented to a lesser extent. Today the labour camp still has structures, albeit in a very poor state of preservation. However, much of the area of the former camp is now covered in trees, which were planted post-war, as well as low vegetation.

Conversely, at the extermination camp of Treblinka II, features above the ground related to the atrocities which took place are not clearly visible. As the Nazis razed Treblinka's death camp in 1943, little physical evidence of the genocide perpetrated there remained on the surface. The gas chambers, a fake railway ticket office and other structures which were built on site were demolished and the ground was levelled. The area today is mostly characterized by the memorial built to commemorate the victims. Thus, little was known about the geography of the camps and what evidence of the killings survived.

4. Methodology

To address this issue, an historical and archaeological project began at Treblinka in 2007. Staff from the Centre of Archaeology undertook non-invasive fieldwork at both Treblinka I and II in 2010, 2012 and 2013 in order to identify the locations of the camp boundaries, mass graves and

gas chambers; aims that were successfully achieved [2, 3, 12]. This work involved walkover survey, topographic survey (with DGPS and a Total Station) and geophysical survey. Excavations were also undertaken in 2013 which confirmed the location of one of the gas chamber buildings and identified a number of personal belongings. During this fieldwork season, and a subsequent season in 2017, the methodology described below was employed in order to further characterise the terrain of, and evidence contained within, both camps.

The study described in this paper focuses on the interdisciplinary 3D modelling and visualization work, consisting of a top-down, multi-scale image- and range-based digital documentation method developed to fulfil all the surveying and archaeological needs and exploit all the intrinsic potentialities of the actual 3D modelling techniques.

The first layer of information is represented by LiDAR data acquired in form of 3D point clouds from an aerial platform covering the entire terrain of Treblinka I and II. At ground level, the visible structures have been digitized through photogrammetric techniques and referenced in a known reference system. Where test trenches were opened in 2017, a layer-to-layer image-based 3D documentation was carried out. Finally, an interactive 3D excavation diary was created exploiting a WebGL system for online visualization.

4.1. LiDAR Documentation

In 2013, an airborne LiDAR survey, with a spatial resolution of 0.5 m, was commissioned in order to examine the entire landscape of Treblinka (3.75 square kilometres). Aerial Laser Scanning (ALS) is nowadays a well-known geomatic technique used for the creation of three-dimensional terrain models [13]. It facilitates the production of detailed 3D representations of terrains in the form of georeferenced point clouds, characterized by XYZ coordinates and, where available, intensity information.

Although image-based modelling methods - such as photogrammetry and computer vision-based approaches using Structure from Motion (SfM) and Multi-View Stereo (MVS) - have reached a level of reliability comparable with active sensors [14], ALS still remains the only methodology which allows for the production and extraction of Digital Surface Models (DSM) and Digital Terrain Models (DTM) respectively from a single survey in a reasonable amount of time. One of the main advantages of this technique is the possibility to filter out tree canopies and provide access to areas that were previously inaccessible due to the density of vegetation [15]. Indeed, some of the airborne sensor-emitted radiation might reach the ground before it gets reflected back. This means that it may be possible to record features that are otherwise invisible or inaccessible using traditional survey methods. However, this applies only when the vegetation canopy on ground is not too dense. An accurate representation of the ground level was indeed mandatory for the identification of hidden features at Treblinka.

In particular, analysis of this data focused on the execution site located south of the labour camp that was previously inaccessible using other non-invasive methods due to the presence of trees and dense vegetation. The survey facilitated the production of 3D models that, in simple terms, showed anomalies and earthworks in the landscape [16] (Figure 3).



Figure 3. Treblinka I and II, Digital Surface Model, Execution Camp location

After the initial point cloud was segmented into two different layers (DTM and DSM respectively), a high-resolution orthophoto was re-projected onto the upper layer (DSM), with the final goal of showing a RGB realistic representation of the entire site.

To better analyze, and facilitate the reading of, the terrain's small-scale relief features, an approach according to [17] was followed, exploiting the open-source Relief Visualization Toolbox (RVT) developed by the Institute of Anthropological and Spatial Studies of the University of Ljubljana (<https://iaps.zrc-sazu.si/en/rvt#v>).

At Treblinka I and II, the topography is mainly characterized by a flat landscape with some shallow depressions barely visible at naked eye. For the same reasons, as highlighted in [18], LiDAR data

interpretation based solely on shaded relief has considerable potential to miss important archaeological features in landscapes such as this.

Therefore, the following techniques - which have proven to be successful for archaeological features identification - were applied alone or combined together: (i) Hill-Shading [19], (ii) Local Relief Model [20], (iii) Openness [21], (iv) Local Dominance [22].

According with the results achieved during the data post processing, the most successful and suitable techniques for the Treblinka archaeological landscape were the Local Relief Model (LRM) and Local Dominance (LD).

The generated maps highlighted a series of ground anomalies which were confirmed by walkover survey and, in some cases, excavation [23, 24] (Figure 4). Hundreds of features were recorded which related to the camps and the execution site. Most significantly, these data enhancement techniques revealed the presence of several apparent graves in the woodland to the south of the labour camp.



Figure 4. Treblinka Execution Camp (detail), Local Relief Model (LRM) map (top) and Local Dominance (LD) map (bottom)

Subsequently, to corroborate the aforementioned results, a roughness analysis of the DTM, which still does not represent a standard methodology in archaeological science, was computed. This analysis, realized in the open source CloudCompare software (www.cloudcompare.org), estimates

the roughness of a point cloud by computing a value equal to the distance between each point and the best-fitting plane calculated from its nearest neighbours. Different kernel values (the search radius of the sphere which has the point as barycentre) were applied, with the main aim to highlight ground features at different scales. The final outputs were represented by colour-coded maps which facilitated the visual identification of ground-based surface anomalies (Figure 5).

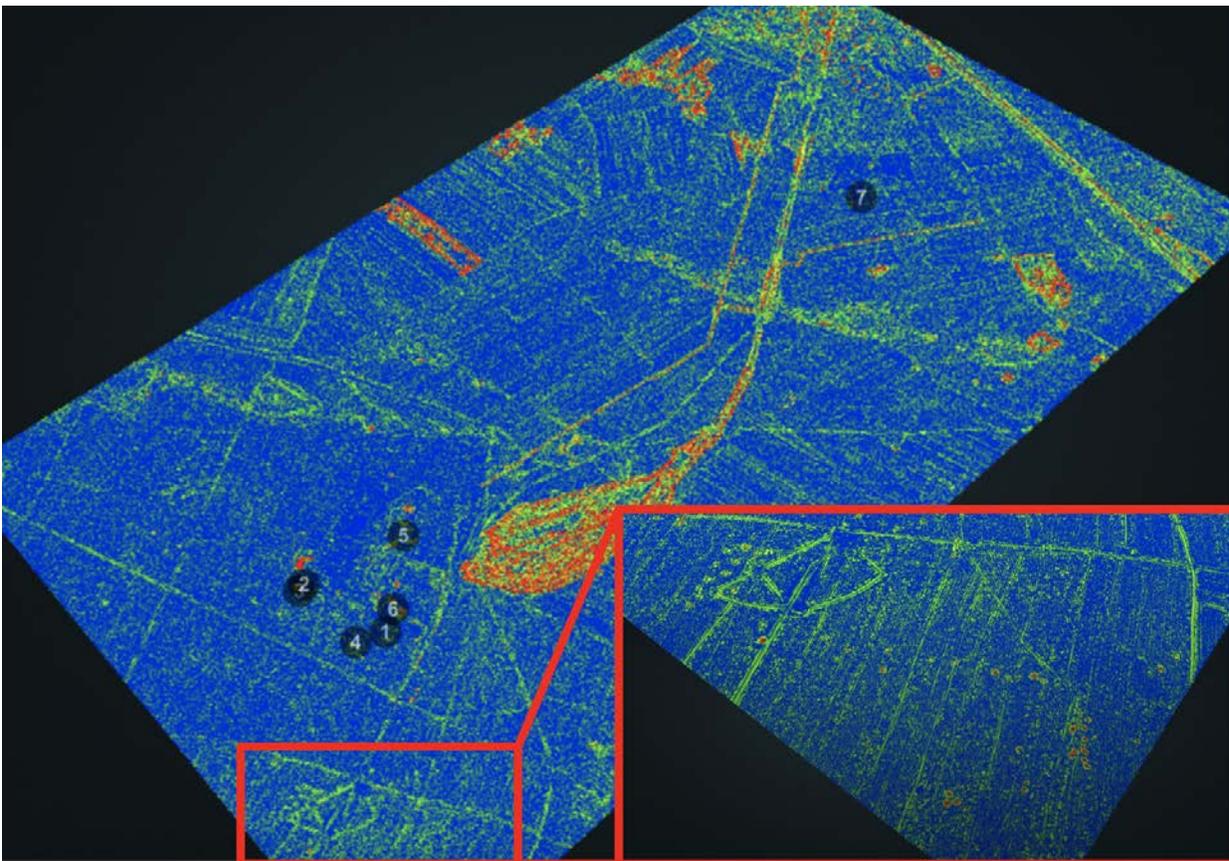


Figure 5. Treblinka I and II, Digital Terrain Model, Roughness Analysis, apparent graves in the woodland south of the labour camp

4.2 Photogrammetric Survey

Today digital photogrammetry can be a feasible and flexible solution, and a quasi-standard procedure may be found to suggest general best practices for systematic 3D surveys [25]. Due to its data acquisition speed and portability, it was chosen as a data collection method which best suited the needs of the presented project. In Treblinka, all photogrammetric data acquisition was coupled with a GPS data survey to ensure accurate location data was obtained to enhance the alignment of the images. Systematic data collection was realized, as shown in Table I.

Structure	Location
kitchen	Labour Camp
Well	Labour Camp
Pool A	Labour Camp
Pool B	Labour Camp
Garage	Labour Camp
Punishment Bunker	Labour Camp
Latrine A	Labour Camp
Trench test (3 Layers)	Extermination Camp

Table I: Digitized Structures and Archaeological Features

4.2.1 The Labour Camp Structures

All the structures detectable above the ground at Treblinka are today located in the labour camp. Some of them are visible at the foundation level as concrete platforms (barracks, stable, garage); others are characterized by walls in elevation (kitchen, pools and punishment bunker); and some others are identifiable by topographic change or surface remnants (well, latrines).

A Canon 5D Mark iv camera, 30-megapixel full frame sensor (6 μ m pixel size), equipped with a Sigma 20mm 1:1.4 DG and Sigma 50mm F1.4 DG HSM | A prime lenses, was used for the

photogrammetric survey. A camera network was planned according with the typology of artefact and with the main aim of obtaining an average ground-sample distance (GSD) of 5 mm (Figure 6). For each structure, Ground Control Points (GCPs) were acquired to scale and georeference the model.

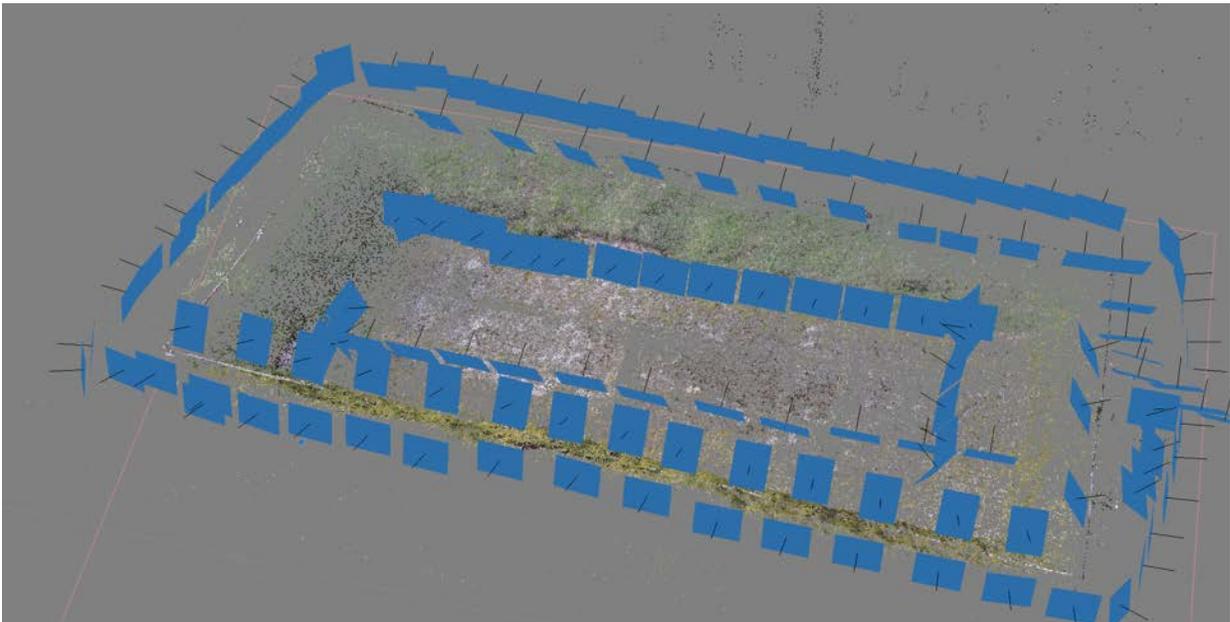


Figure 6. Pool B, Labour Camp, Photogrammetric Camera Network

The adopted image-based 3D reconstruction procedure followed the typical photogrammetric workflow, consisting of three main steps, namely: image correspondences detection, bundle adjustment and dense image matching. Although their level of automation reached high standards, an essential pre-requisite to support these tasks and improve the quality of the final results (especially in terms of precision, accuracy and reliability) was the quality of the input images. After an initial histogram's stretching and white balancing, de-noise processing followed by an advanced image content enhancement technique, were applied.

The latter adopts the well-known adaptive Wallis Filtering algorithm [26], in its improved version, implemented in the open-source photogrammetric tool GRAPHOS [27] available at <https://github.com/itos3d/GRAPHOS>.

Each image dataset was finally processed with Agisoft PhotoScan in order to produce a georeferenced 3D model of each structure (Figure 7) and high-resolution ortho-photos with a pixel dimension of ~1 cm.

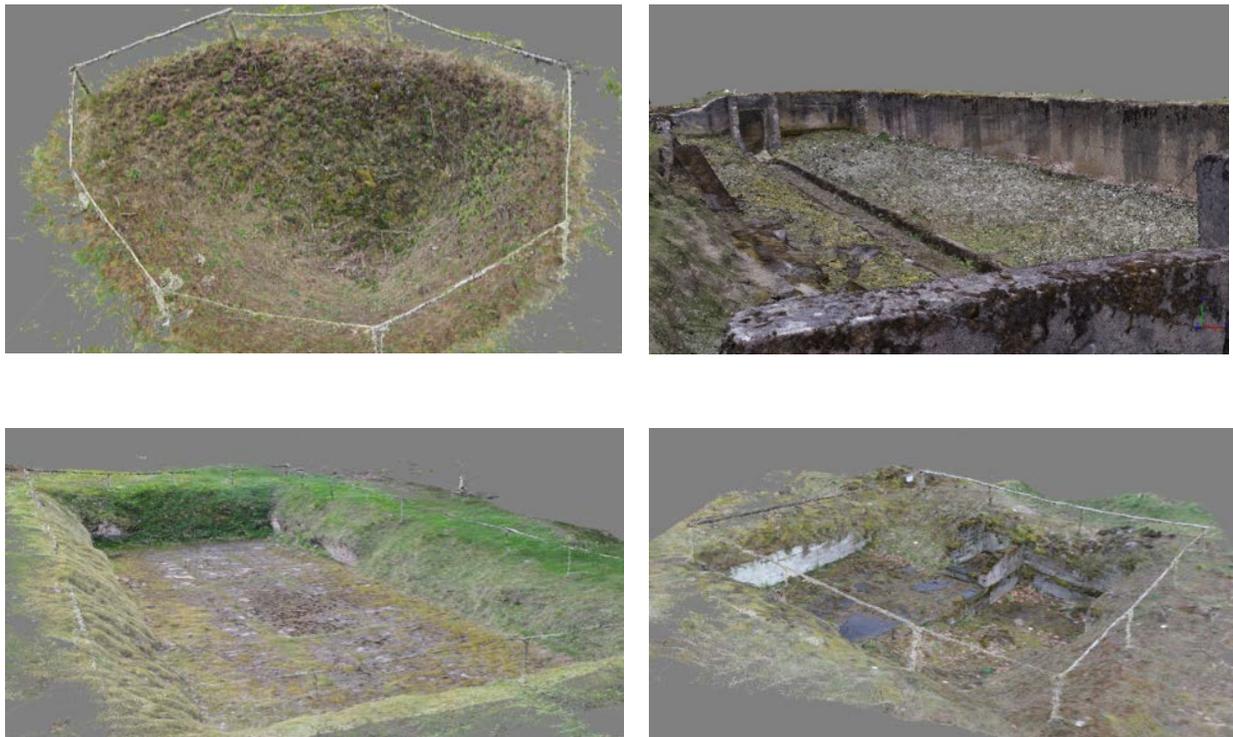


Figure 7. Well (Top left), Kitchen (Top right), Pool B (Bottom left), Punishment Bunker (Bottom right), Labour Camp, 3D Models Point Clouds

4.2.2 Extermination Camp Test Trench Stratigraphic 3D Documentation

At the extermination camp, the team from the Centre of archaeology was granted permission to realize some test trenches with the main aim of identifying the remains of the gas chambers where victims were murdered. Due to the unique chance to excavate in such a scenario and the

considerable ethical issues and commitments associated with the religious and commemorative significance of the site, a layer-by-layer documentation of the archaeological excavation was planned to create a reliable representation of the features as they were gradually exposed (Figure 8).



Figure 8. Test Trench, Extermination Camp, Stratigraphic 3D Documentation

An appropriate camera network was planned to acquire both oblique and vertical images.

Artificial targets fixed along the perimeter of the test trench were recorded with a GPS.

Due to the average distance camera-object of 2.5 meters, a GSD of 2 mm was achieved. After image pre-processing, similar to that described above, a 3D model composed of three separate layers was created in the WGS 84 / UTM zone 34N reference coordinate system. Although each 3D layer was created independently, thanks to the same global position, it was automatically aligned when imported in a single workspace. The virtual excavation was hence automatically recomposed without the need for any further adjustment or registration.

5. Data Integration and Visualization

With the main aim of creating an easy-to-use interactive platform for Treblinka I and II, open both for use by professionals and the general public, all the models and 3D information were organized

in a single, web-based, interactive application. According to the initial pyramidal approach, the user is able to browse the virtual objects from a landscape to a layer-by-layer scale in the same virtual environment clicking on the plotted hot-spots.

The web-based system, which can be exploited using traditional WebGL enabled browsers, is built over two open-source viewers respectively, allowing for the interactive streaming of point cloud (Potree) and mesh models (3DHop). The decision to design the digital platform using both aforementioned viewers is based on the objective of creating an open and scalable system which is able to display different kinds of 3D objects in the same web environment.

5.1. 3D Point Cloud Viewer

Through the proposed database architecture, high-resolution 3D models consisting of millions of points and RGB values are available online via the open source WebGL based Potree viewer [28]. Potree is a point-based rendering solution specifically developed for visualizing large point clouds using standard web-based technologies. It is capable of easily providing a responsible interactive viewer that only requires a traditional web browser (WebGL enabled), freeing the user from any configuration issues or specific software. Potree point cloud files are encoded in an octree data structure using a dedicated converter [29], guaranteeing a high level of content protection and security.

The selected viewer features the ability to (i) visualize 3D point clouds online, (ii) measure distance, compute volumes and areas, (iii) extract, visualize and download sections, (iv) link with external resources (metadata) through dedicated hot-spots located on the 3D interactive point cloud (Figure 9).

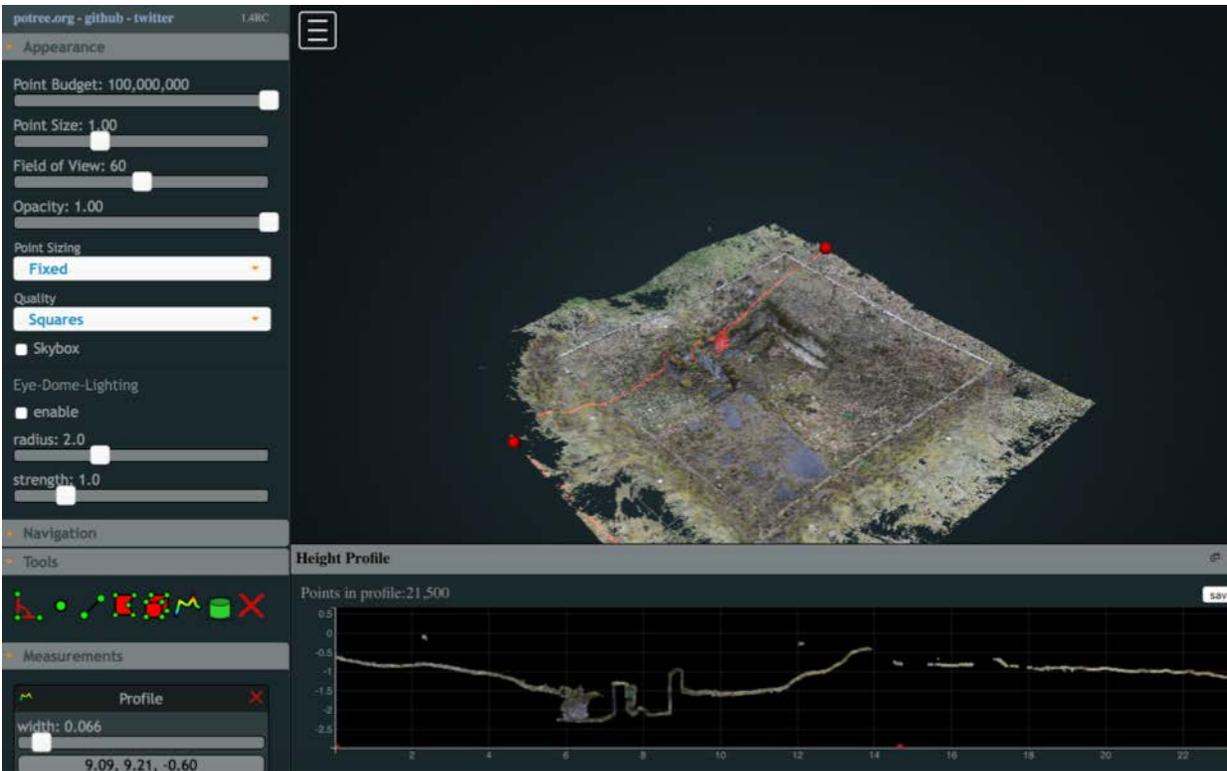


Figure 9. Punishment Bunker (Point Cloud), Labour Camp, Potree Viewer, Section Tool

The DSM and DTM models of the landscape of Treblinka I and II camps have been enriched with active hotspots which allow the user to switch Level of Detail (LOD) and explore either structures or the archaeological excavation. All layers are organized in a menu which allow them to be switched on and off accordingly.

Another layer of information is represented by the possibility to visualize High Resolution images online directly through the web browser, without installing any additional plug ins and without any loss of quality.

The open-source web-based viewer OpenSeaDragon (<https://openseadragon.github.io>) has been used. It supports image formats such as JPEG/JPG, PNG, TIFF, GIF. Direct links are provided into Potree environment as hotspots. Large images are stored by creating an image pyramid, using

a technique similar to frustum culling. High resolution images are subdivided into a set of tiles stored in subfolders which are visualized on the web browser according to the user input. Hence, the client's machine downloads only data needed to create the current view, disregarding portions of the image outside the field of view (Figure 10).



Figure 10. Garage, Labour Camp, High Resolution Orthophoto, Detail

5.2 3D Mesh Model Viewer

In order to envision the platform as a flexible tool for future enrichment and expansion, the 3D Hop (Heritage Online Presenter) mesh viewer was chosen [30]. This system, developed in the framework of the EC NoE project "V- MUST.NET - Virtual Museum Transnational Network" by the Visual Computing Laboratory - ISTI – CNR, is an open-source tool for the visualization of very large 3D models directly inside HTML pages. It is released under the GPL license [31]. 3D Hop is a multi-platform system and a cross-browser application which can be customized for

different uses and purposes [32]. Although 3D Hop supports ply files (geometry and per vertex colour info) as a single resolution model, it is possible to convert it into a Nexus file format (nxs) which allows the streaming of multi-resolution 3D meshes over HTTP without sharing original data. Converted files remain stored on owner's server, preserving IPR [33].

According to the models available online, the user could exploit either Potree or 3D Hop. Both the viewers indeed allow the same kind of operation and analysis to be performed (Figure 11).



Figure 11. Garage (Mesh Model), Labour Camp, 3DHop, Measurement Tool

6. Conclusions

This work proposed a comprehensive and interactive tool for the visualization of the Treblinka I and II camps, and 3D models exploiting an open-source web-based platform composed of different kinds of viewers.

First of all, a pyramidal multi-level and multi-sensor 3D modelling strategy through the use of different kind of active and passive sensors has been illustrated, highlighting the different LOD achievable, spanning from few centimetres to few millimetres. A scientific analysis of the Digital Terrain Model for the identification of ground features and anomalies was then described.

Thereafter, the paper focused on the visualization platform which was built to allow the final users, belonging to the scientific community or a public audience, to analyse the 3D environment from a landscape to a layer-by layer perspective.

The proposed technologies have shown the reliability of data streaming of high resolution three-dimensional models, providing smooth online interaction and visualization.

In the future, featured works will be represented and the platform will be enriched with traditional metadata such as text, audio and video files and material as part of the European collaborative research project ‘Accessing Campscapes: Integrated Strategies for Using Europe’s Conflicted Heritage’ (<http://www.campscapes.org/>).

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8. Bibliographical Note

Dr. Dante Abate

Dr. Dante Abate was appointed as a Marie Skłodowska-Curie Research Fellow in 2017 to work on the “Digital Forensic Archaeology Project (Dig-For-Arch)” at the Centre of Archaeology at Staffordshire University. Over the last decade, Dr. Abate’s research activity and practice has focused on applying 3D modelling techniques in the field of humanities and cultural heritage. He has published extensively on the subjects of archaeological site survey, Terrestrial Laser Scanning and 3D modelling.

Professor Caroline Sturdy Colls

Professor Sturdy Colls is a Professor in Conflict Archaeology and Genocide Investigation at Staffordshire University specializing in Holocaust studies. She is also the Director of the Centre of Archaeology. Her research focuses on the application of interdisciplinary approaches to the investigation of sites of mass violence. She has published and teaches on the subjects of Holocaust archaeology, forensic archaeology and missing persons investigations.

References:

- [1] Arad, Y., 1987. Belzec, Sobibor, Treblinka. The Operation Reinhard Death Camps, «Indiana University Press».
- [2] Sturdy Colls, C., 2014. “Gone but not forgotten: Archaeological approaches to the landscape of the former extermination camp at Treblinka, Poland”, *Holocaust Studies and Materials*, vol. 3, p. 239-289.
- [3] Sturdy Colls, C., Colls K., forthcoming. “The Heart of Terror: A Forensic and Archaeological Assessment of the Old Gas Chambers at Treblinka”, Vareka, P., Symonds, J. *Dark Modernities*. London «Palgrave Macmillan».
- [4] Ramos, M., Remondino, F., 2015. “Data fusion in Cultural Heritage – A Review”. *ISPRS Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XL-5/W7, pp. 359-363. 25th CIPA Symposium, Taipei, Taiwan.
- [5] Gruen, A., Remondino, F., Zhang, L., 2005. “The Bamiyan project: multi-resolution image-based modelling”. *Recording, Modeling and Visualization of Cultural Heritage*, 18, ISBN 0 415 39208 X, pp. 45–54.
- [6] Bonora, V., Tucci, G., Vaccaro, V., 2005. “3D data fusion and multi-resolution approach for a new survey aimed to a complete model of Rucellai’s chapel by Leon Battista Alberti in Florence”. *Proc. of CIPA XX Int. Symposium*, Turin, Italy.
- [7] El-Hakim, S., Remondino, F., Voltolini, F., 2008, “Integrating Techniques for Detail and Photo-Realistic 3D Modelling of Castles”. *GIM International*, Vol.22(3), pp. 21–25.
- [8] Guidi, G., Remondino, F., Russo, M., Menna, F., Rizzi, A., 2008. “3D modeling of large and complex site using multi-sensor integration and multi-resolution data”. *Proc. 9th Int. Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)*, pp.85-92, Braga, Portugal.

- [9] Guidi, G., Remondino, F., Russo, M., Menna, F., Rizzi, A., Ercoli, S., 2009. "A Multi-Resolution methodology for the 3D modeling of large and complex archaeological areas". *International Journal of Architectural Computing*, Vol. 7(1), pp. 39-55.
- [10] Remondino, F., Gruen, A., von Schwerin, J., Eisenbeiss, H., Rizzi, A., Sauerbier, M., Richards-Rissetto, H., 2009. "Multi-sensors 3D documentation of the Maya site of Copan". *Proc. of 22nd CIPA Symposium*, 11-15 Oct., Kyoto, Japan.
- [11] Cantoro, G., 2017. "Ground and Aerial Digital Documentation of Cultural Heritage: Providing Tools for 3D Exploitation of Archaeological Data". *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLII-2/W3, 2017 3D Virtual Reconstruction and Visualization of Complex Architectures, 1–3 March 2017, Nafplio, Greece.
- [12] Sturdy Colls, C., 2015, *Holocaust Archaeologies: Approaches and Future Directions*. New York «Springer».
- [13] Wehra, A., Lohrb, U., 1998. "Airborne laser scanning—an introduction and overview". *ISPRS Journal of Photogrammetry and Remote Sensing*, Volume 54, Issues 2–3, July 1999, Pages 68-82.
- [14] Remondino, F., 2011. "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning". *Remote Sensing*, 3(6), pp. 1104-1138.
- [15] Bao, Y., Bao, Guoping, L., Chunxiang, C., Xiaowen, L., Hao, Z., Qisheng, H., Linyan, B., Chaoyi, C., 2008. "Classification of LiDAR point cloud and generation of DTM from LiDAR height and intensity data in forested area". *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 37, Part 3B, pp. 313–318.

- [16] Crutchley and S., Crow, P., 2010. *Light Fantastic: Using Airborne LIDAR in Archaeological survey*, Swindon: English Heritage.
- [17] Kokalj, Ž., Ralf H., 2017. *Airborne laser scanning raster data visualization: A Guide to Good Practice*. Ljubljana: Založba ZRC.
- [18] Challis, K., Kokalj, Ž., Kinsey, M., Moscrop, D., Howard, A.J. 2008. Airborne lidar and historic environment records. *Antiquity* 82, 318: 1055-1064.
- [19] Yoëli, P. 1965. Analytische Schattierung. Ein Kartographischer Entwurf. *Kartographische Nachrichten* 15 (5): 141–148.
- [20] Hesse, R. 2010. LiDAR-Derived Local Relief Models - a New Tool for Archaeological Prospection. *Archaeological Prospection* 17 (2): 67–72.
- [21] Yokoyama, R., M. Shirasawa and R. J. Pike. 2002. Visualizing Topography by Openness: A New Application of Image Processing to Digital Elevation Models. *Photogrammetric Engineering and Remote Sensing* 68: 251–266.
- [22] Hesse, R., 2016. Visualisierung Hochauflösender Digitaler Geländemodelle Mit LiVT. In *Computeranwendungen Und Quantitative Methoden in Der Archäologie. 4. Workshop Der AG CAA 2013*, edited by U. Lieberwirth and I. Herzog, Edition Topoi, 109–128. Berlin Studies of the Ancient World. Berlin: Topoi.
- [23] Sturdy Colls, C., Colls, K., 2013. *Finding Treblinka: Archaeological Evaluation (Project No. P13-02)*. Stoke-on-Trent, Staffordshire: Centre of Archaeology, Staffordshire University.
- [24] Sturdy Colls, C. 2016. 'Earth conceal not my blood': forensic and archaeological approaches to locating the remains of Holocaust victims' In: Dreyfus, J-M. and Anstett, E. *Human remains in society: Curation and exhibition in the aftermath of genocide and mass-violence*. Manchester: Manchester University Press.

- [25] Remondino, F., Spera, M.G., Nocerino, E., Menna, F., Nex, F., 2014. "State of the art in high density image matching". *The Photogrammetric Record*, Vol. 29(146), pp. 144-166, DOI: 10.1111/phor.12063.
- [26] Wallis, R., 1976. An approach to the space variant restoration and enhancement of images. In: *Proc. of the Symposium on Current Mathematical Problems in Image Science*, pp. 329 – 340
- [27] González-Aguilera D., López, L., Rodríguez-Gonzálvez, P., Guerrero, D., Hernández-López, D., Remondino, F., Menna, F., Nocerino, E., Toschi, I., Ballabeni, A., Gaiani, M., 2016. Development of an all-purpose free photogrammetric tool. In: *The Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 41(B6), pp.31-38.
- [28] Schutz, M., Wimmer, M., 2015. "Rendering large point clouds in web browsers". In: *Proc. 19th CESC*, pp. 83-90.
- [29] Schutz, M., 2014. "PotreeConverter - Uniform partitioning of point cloud data into an octree". Available at: http://potree.org/downloads/converter_documentation.pdf [Last Accessed: 15/12/2017]
- [30] Di Benedetto, M., Cignoni, P., Ganovelli, F., Gobbetti, E., Marton, F., Scopigno, R., 2009. Interactive remote exploration of massive cityscape. In: *Proc. of the 10th VAST Conference*, pp. 9-16.
- [31] Callieri, M., Ponchio, F., Cignoni, P., Scopigno, R., 2008. "Virtual Inspector: a flexible visualizer for dense 3D scanned models". *IEEE Computer Graphics and Applications*, IEEE Press, January/February 2008, pp. 44-55.
- [32] Potenziani, M., Callieri, M., Dellepiane, M., Corsini, M., Ponchio, F., Scopigno, R., 2015. "3DHOP: 3D Heritage Online Presenter". *Computers & Graphics*, 2015.

[33] Cignoni, P., Ganovelli, F., Gobbetti, E., Marton, F., Ponchio, F., Scopigno R., 2005. "Batched Multi Triangulation". Proceedings IEEE Visualization, page 207-214.