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FROM ARCHIVES SOURCES TO VIRTUAL 3D RECONSTRUCTION OF MILITARY HERITAGE – THE CASE STUDY OF PORT BATTERY, GDAŃSK

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ABSTRACT

The research presented in the article focuses on the development of methodological protocols - from survey to digital reconstruction - for the enhancement and protection of built heritage. Through the realisation of virtual reality-based digital models, it is possible to narrate the evolution and transformation of those places that constitute our historical memory. The European Project H2020 Prometheus, focused on the documentation of the Gdańsk fortresses Route, allowed applying these strategies to the Port Battery case study, presented in this paper. The coastal battery, built in the 19th century, is a brick ruin located in the restricted port area of Gdańsk, witness to several historical processes of transformation. To be able to represent the evolution of the building through history, the operational method regarded the digital acquisition of the building to obtain a detailed model representing the state of the battery. Then the archive research and the available historical maps allowed not only to make a comparison between the previous stages of construction and the actual situation but also to digitally reconstruct what has been destroyed. In this way, through Virtual Reality via Head Mounted Display it is possible to obtain an immersive, but accurate, experience of the digital reconstruction being able to re-live the history of a place.

1. INTRODUCTION

The appearance of 3D computer technologies has greatly impacted the field of architectural heritage by enabling the creation of highly accurate and detailed digital models of historical structures. This allows for the preservation of heritage sites in a digital format, which can be used for research, documentation, and educational purposes. It also allows for the analysis of structural elements and materials, aiding in the identification of potential preservation issues and the development of conservation plans. Additionally, 3D technologies enable the visualization and presentation of heritage sites in new and innovative ways, such as through virtual reality and augmented reality experiences.

Overall, 3D computer technologies have opened up new possibilities for the study and appreciation of architectural heritage and deliver new tools in the management and architectural design processes such as BIM, HBIM (Acampa, 2020), and according to the urban scale GIS and HGIS. Moreover, an increasing trend is to establish open-source databases of reconstructed heritage sites, which promotes broader accessibility and fosters collaboration among researchers and the public (Checa, 2021).

Among architectural heritage structures such as churches, town halls, and tenement houses, as well as those that have been adapted and repurposed, fortifications indicate a unique challenge due to their original and specific function, making them difficult to alter, which causes the possible neglection and decay. However, their presence can also pose challenges in terms of preservation and maintenance, as well as issues related to public safety and access. According to heritage conservation principles (Jokilehto, 2007) and the outdated function, it would be unnecessary to undertake the physical reconstruction of the fortification, thus the moment of experiencing the integral heritage object could be obtained via digital tools (Bruno et al 2010; Amdo et al. 2009; Arbace 2013; Landrieu, 2012; Pierdicca, et al. 2016). To start enhancement and valorisation actions, the research will focus on the application of an operational workflow aimed at the re-discovering of this military heritage through the potential offered by the digital. The process of investigation involves the integration of different survey methodologies suitable to reach the most complete and detailed knowledge of the heritage artefact (Parrinello et al., 2019).

Figure 1. Remains of Port Battery, November 2022.

2. METHODOLOGY

The research was organised in three different methodological steps: a first phase of historical analysis, a second phase of a digital survey of the current structure, and a third phase through which it was possible to elaborate a 3D model to compare the historical sources with the current data.

2.1 Historical analysis

The research was primarily based on previous works that covered the topic of Port Battery (Hirsch 1995, 1996; Woźniakowski, Hirsch, 2023). In addition, an archival query was conducted in the State Archive in Gdańsk to obtain cartographic materials illustrating the history and evolution of the research objects.

Because the object under research had a military nature, there were only a limited amount of materials available that provided a complete depiction of the emplacement. All of these materials including previous research were used as a foundation for identifying the researched structures.

2.2 Digital survey

Port Battery and its area had never before been digitally surveyed. The team carried out a topographical documentation campaign with TLS and MLS laser scanning instrumentation. The use of multiple instruments made it possible to quickly create a complete documentation of the area and to have comparable data to verify the metric reliability of the digital product (Picchio, Pettineo 2023).

2.3 Modeling and data comparison

The data from the acquisition phase were processed for individual datasets and then integrated into a single global point cloud (Parrinello, Picchio, 2019).
From the digital duplicate thus obtained, post-production processes were initiated to define digital models of the Battery.

3. THE ANALYSIS OF PORT BATTERY EVOLUTION

Today, the Port Battery (pol. Bateria Portowa, ger. Hafen Batterie) is a rather peculiar ruin visible from a cliff spanning along the coast of the Baltic Sea in Gdańsk, located at the protected area of Gdańsk's Port's free customs area. Thankfully to the very restricted area, the Battery is preserved in rather interesting condition since the equipment was not stolen and destroyed by vandals. Unfortunately, the battery itself is badly damaged due to the no conservation and short-sighted activities of the seaport to facilitate communication for trucks operating on the quays, resulting in further degradation and dismantling remains of the previous fortification, causing the look of a rather crippled battery. (Hirsch, 1995, 1996, Woźniakowski, Hirsch, 2023)

3.1 The Battery through its history

In 1772, Prussia acquired Nowy Port and Westerplatte during the first partition of Poland, and in 1793, they finally conquered Gdańsk during the second partition. Previously, the mouth of the Vistula was defended by the Wisłoujście fortress, until the coastline was moved towards the sea, which also resulted in the need to create new fortifications. (Samól, 2021,2022). The initial Prussian ramparts were built during this time, starting with Westerplatte (Samól et al. 2023) between 1788 and 1790, followed by Nowy Port between 1803 and 1806. The Port Battery construction began in 1869-1870 to reinforce the already existing chain of surrounding ramparts and the port entrance. The fortification underwent modifications and upgrades throughout its lifetime, resulting in an extended final phase before its eventual destruction.

The Port Battery's original design, dating back to 1870, featured a pentagon plan with a symmetrical layout to house 10 Prussian cannons on carriages. Battery was located near the coast and it was surrounded by a dry ditch. To defend the moat, a double-sided caponier with a triangular shape was built beyond the earthwork fortification's outline, connected to the courtyard using a covered potern (tunnel).

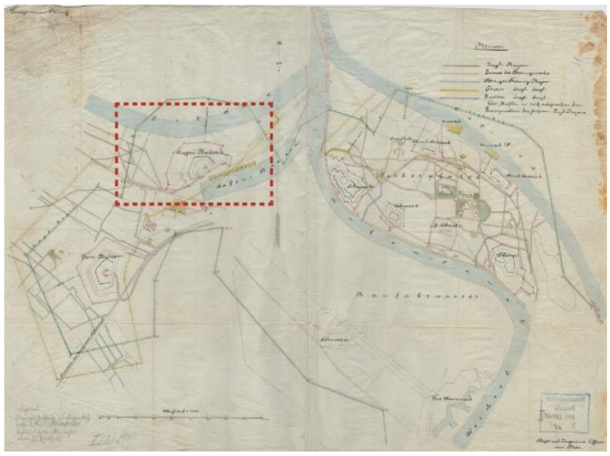


Figure 2. Location of the initial stage of Port Battery in Gdańsk. Dated around 1880. State Archive in Gdańsk, signature 10/1121/0/-/172.

The left forehead had five gun emplacements at the wallworks covered with a sloped firing crest separated by raised traverses and brick casemates that served as shelters equipped with staircases and munitions lifts. The area also had munitions laboratories for filling artillery projectiles and shelters covered in the shoulder. The right shoulder had the same number of gun emplacements and munitions laboratories and shelters, but the ground floor was adapted for crew quarters with south-facing windows. The main entrance was covered by the entry block, which served as crew quarters, and the caponier covered the entrance and moat.
Construction of the battery was interrupted by the outbreak of the Franco-Prussian War on July 19, 1870. After the Kingdom of Prussia emerged victorious, construction resumed following the end of the war and the peace agreement on May 10, 1871, and the battery was eventually completed in its initial form.

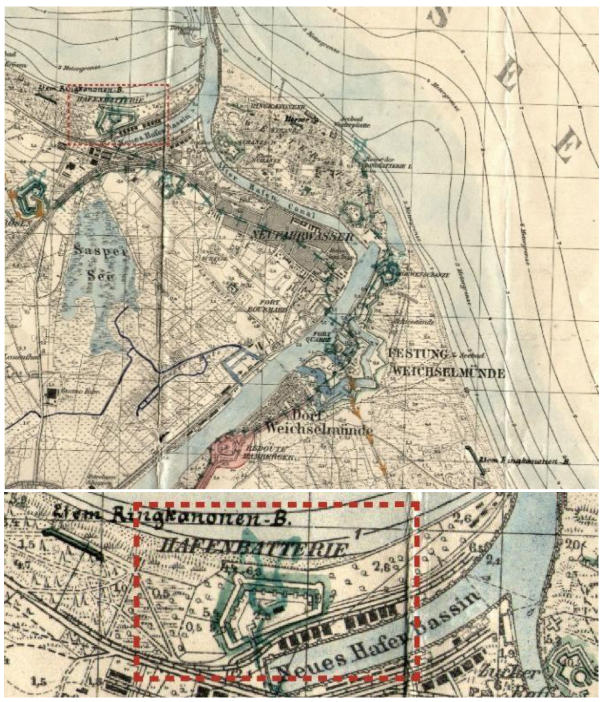


Figure 3. Situation plan of coastal fortifications around Vistula mouth around 1900. Port Battery is represented with the prolonged right shoulder. State Archive in Gdańsk, signature 10/1121/0/-/1

In 1876 the battery was equipped with stationary artillery emplacements and at the end of the 1880s the right shoulder was extended to better accommodate six long-range rifled cannons, namely the Prussian-made *21 cm Ringkanone*. This expansion led to the fortification taking on an asymmetric shape. The gun emplacements were reconstructed with concrete flooring and equipped with barbettes and rails to accommodate the new artillery. The crew quarters and workshops were also extended, following the same architectural composition and details, with serrated brick cornice and pilaster strips creating a very rhythmic facade featuring two segmental arc windows per module. The traverses were upgraded to improve their shelter function, with a concrete roof capping designed to withstand bigger projectiles. The left shoulder was not modified to accommodate the new artillery due to the main focus and the biggest perceived threat coming from naval units.
The Port Battery and other similar batteries of its era were rendered obsolete and no longer utilized for military purposes as a result of the ordinances passed on February 28 and March 12, 1907. Their function was replaced by newly constructed reinforced concrete batteries. After World War II, during which the battery was likely utilized by Nazi soldiers, the Port of Gdańsk took over the area, and it was repurposed as a warehouse (Hirsch 1995, 1996; Woźniakowski, Hirsch, 2023).

3.2 State of Preservation and Causes of Decay.

The Port Battery remnants are limited to the central section, featuring a partially preserved potern and a short segment of the brick-made right shoulder, which previously served as crew quarters. At the top, three-gun emplacements are still intact, complete with the remains of the rails that once accommodated the cannons. However, the part of the traverses and shelters are damaged.
Thankfully, the Port Battery was situated in an enclosed area, which prevented significant looting and dismantling of metal components. Some of the original furnishings have been preserved, such as cast-iron spiral stairs in one of the shelters from the initial construction period, as well as a device for transporting missiles from the ground floor to the shelter. Authentic window and door woodwork, as well as wooden floors, have also been retained in certain rooms. The structures are now safeguarded by a conservator, and demolition is prohibited. As the Port Battery is located within the enclosed area of the port, it is not accessible to the public.

4. THE DIGITAL ACQUISITION OF THE PORT BATTERY

The authors performed a comprehensive examination of the battery and its surroundings by utilising mobile equipment, which enabled the team to complete the survey and data acquisition in a single working day. Before the survey, the team assessed the methods and acquisition strategies for each device. The survey needed to be carried out fast enough to not interfere with the dockworker's activities since the Battery is located in a restricted and controlled seaport zone.

4.1 3D Point Cloud

The TLS LIDAR (RTC360) acquisition campaign allowed the documentation of the external walls of the structure and its surroundings. The operator placed the scanner following a polygonal path parallel to the outer walls of the site, for a total of 49 scans. The use of polygonal paths ensured a reduction and compensation of the metric error during the post-production phase of alignment; this metric verification also allowed to avoid black and white targets placement on-site, using instead morphological points (Parrinello, Cioli, 2020).
The survey of the interior was conducted through MLS LiDAR (BLK2GO). The operator carried out seven closed paths overlapped one another with an average distance of 2 meters from architectural surfaces (Dell’Amico, 2021). All paths started from outside the battery to ensure the acquisition of those morphological points required to integrate the data obtained from TLS. To georeferenced the whole dataset a topographic acquisition campaign was conducted using Leica Geosystem GNSS GS07, allowing the acquisition of GPS point coordinates. Considering the moderate size of the building and surrounding area (about 3,000 sqm), 5 GPS points have been recorded. The recorded points were placed along the boundary of the battery and on top of the roof trying to follow a polygonal net to have better control and error compensation. The points acquired with a GPS geostation guarantee the later georeferencing of the entire database (Parrinello, Bertacchi, 2014; Parrinello et al. 2020).

4.2 Close-range Photogrammetry

The area where the Port Battery ruins are located has access restrictions due to its current use as a seaport. For the same reason, the use of drones is also forbidden.

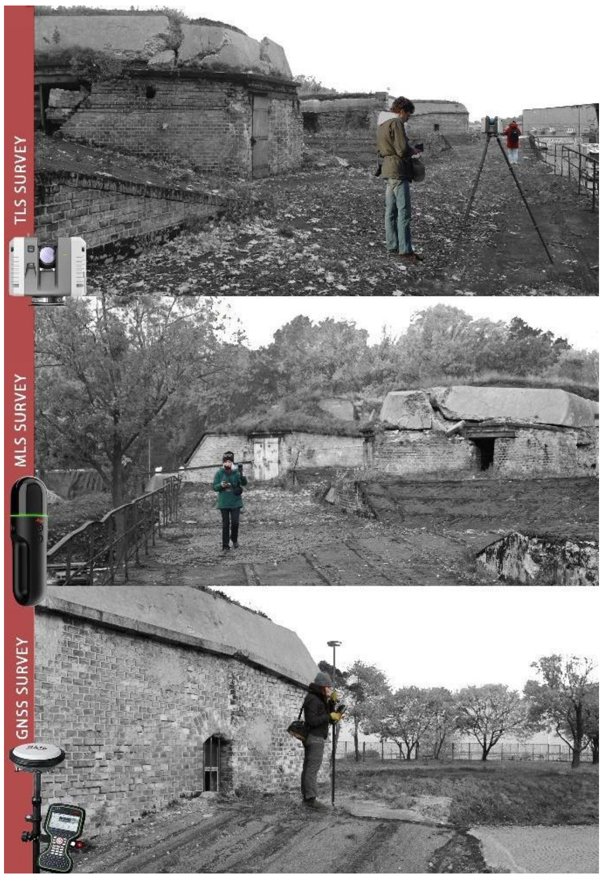


Figure 4. Acquisition phase with the laser scanner and GPS instrument.

This precluded the authors from acquiring photographic data on the roof and elevated portions of the structure.
The photogrammetric acquisition and processing operations are therefore all to be referred to as a methodological process carried out "from the ground" (Remondino, 2011; Parrinello, De Marco, 2021). The use of photogrammetric techniques from the ground

allowed the operators to acquire 671 photographs, with an overlap between contiguous photos of approximately 70%. During the acquisition, which involved the use of a 24.2 MP full-frame Panasonic Lumix S5 mirrorless camera, the operator maintained a constant focal length of 20 mm (GSD < 0,02).
The large size of the sensor, whose format is currently the largest in existence for commercial cameras, allows a high quantity of light to be collected, resulting in increased image quality.
This feature is particularly important in the post-production phase, as it facilitates the software algorithm used to construct the three-dimensional photogrammetric model (Parrinello, Picchio, 2015). The advantage concerns the better interpretation of overlaps and the possibility of generating textures of 4k definition.
The digital duplicate obtained presents data gaps, relating to some portions of the coverage. This lack in the digital was then partly supplemented by using the data acquired in the coverage with laser instrumentation. However, even in this case, it is necessary to consider two important aspects for the reconstruction: the degraded condition of many portions of the architecture (e.g. the ruins of the battery are missing the concrete covers for the artillery positions) and the massive presence of vegetation on the flat roof and the access ramps to the latter.

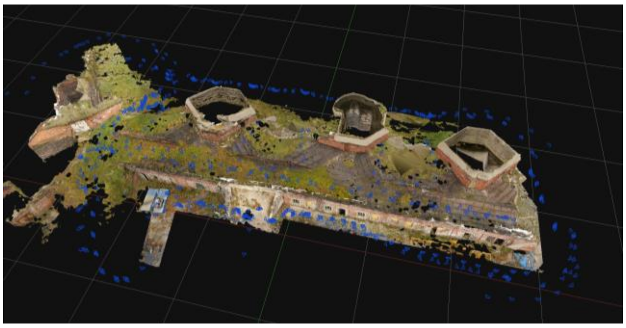


Figure 5. Photogrammetric elaboration for Port Battery using 3DF Zephyr software.

5. POSTPRODUCTION OF ACQUIRED DATA

The dataset was processed into an individual database according to the instrumentation (TLS and MLS). After being referenced through morphological points and cloud-to-cloud alignments (Leica Cyclone software), the point clouds from the two datasets were merged into a single global point cloud (De Marco, Pettineo, 2019).
The use of polygonal paths for the TLS scanning operations (total of 49 scans, with an average density of 10 m. points/sqm) reduced the overall metric error alignment (error max: 1 - 2 cm) and ensured an accurate referencing and uniform metric reliability in the final point cloud (Sammartano, Spanò, 2018). TLS scans included RGB data that allowed more detailed colourimetric information, useful for decay mapping of the surface and evaluations on the structure preservation (Doria et al., 2022). MLS, compared to TLS, has a lower density: less than 2 mln points/sqm, with RGB information.
The MLS data from the survey, compared with those from TLS, have reasonable reliability (average deviations of 3-10 cm) both at architectural and detail levels (Parrinello, Dell'Amico, 2019).
The global point cloud was then georeferenced using GPS points acquired on-site.
The georeferencing of the final point cloud (MLS and TLS) was performed on Leica Cyclone software importing the .txt coordinates of all points as a point system. Within the general point cloud, the position related to the GPS point was marked as a vertex. After the import phase, the GPS coordinate point system was set as a reference scan word ("homeword") for the registration alignment process. Consequently, all the vertices placed on the point cloud are "shifted" in the right coordinate system (average deviation 10-15 cm).
It is necessary to consider that the error obtained may depend on the position/number of points chosen, as well as on the instrumentation: the model used has an average default error of 2-10 cm, additionally to the error due to the instrument's bubble setting, which is not automatic, but carried out by the operator and highly subject to inaccuracies.
The obtained data was later put into further processing to acquire mesh models based on point cloud to mesh technique and simplified and thus optimised to allow a 3D graphical engine to visualise data, and get ready for 3D printing (Doria et al., 2023).
The following methodology was to recreate the whole structure of the Port Battery using 3D drawing giving all the important visual data recreating the development phases.

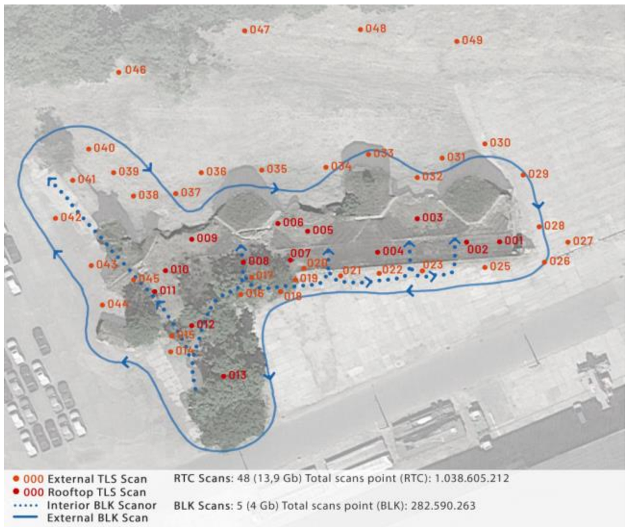
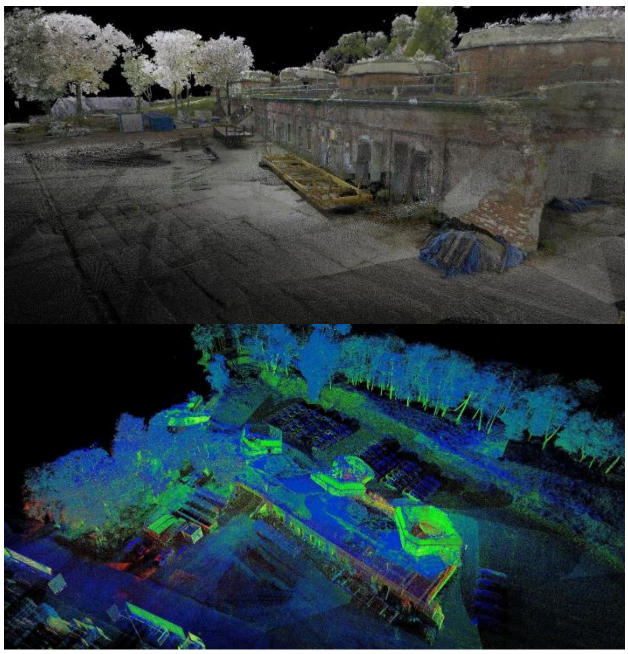


Figure 6. TLS scan position and MLS path.



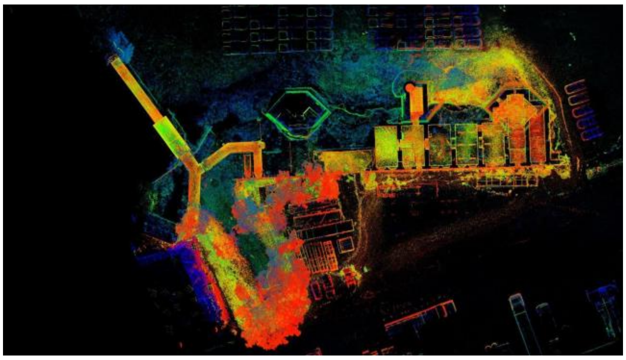


Figure 7. Results of TLS and MLS point cloud registration process in Leica Cyclone Software.

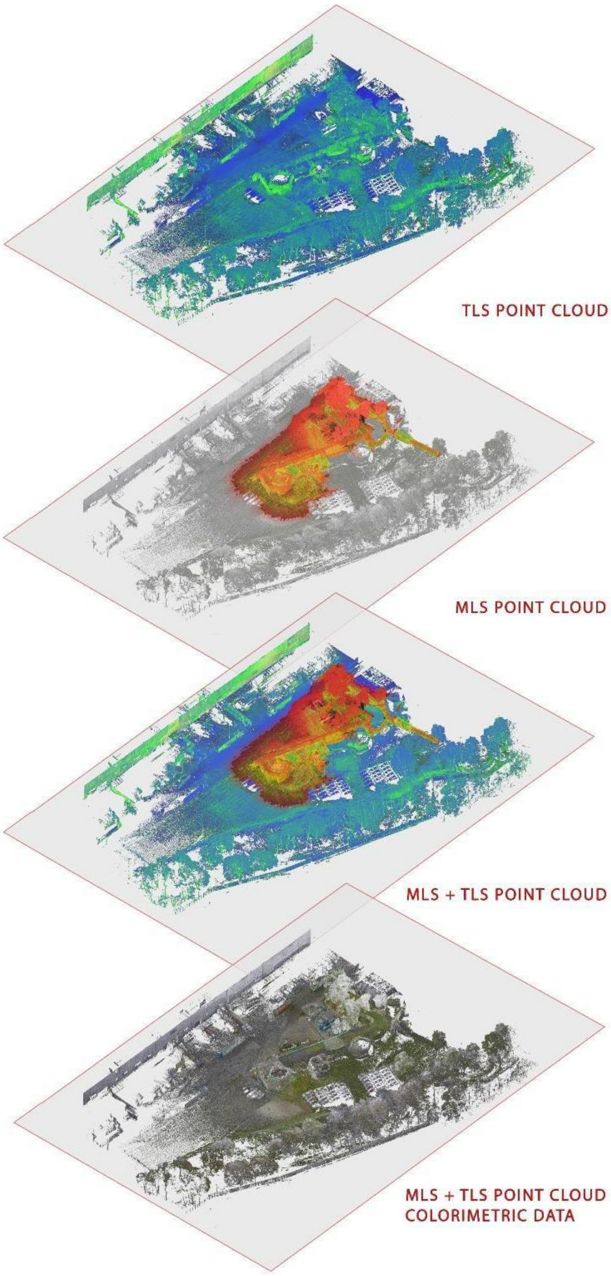


Figure 8. Port Battery point cloud database.

6. 3D RECONSTRUCTION BASED ON THE HISTORICAL SOURCES

Right after gathering all the possible archival sources acquired via the archival query and historical studies (Hirsch 1995, 1996; Woźniakowski, Hirsch 2023) and acquiring a fully registered laser scan, it was possible to start digital reconstruction. The first action concerned the construction of the terrain model. ArcGIS was used to obtain the terrain model based on the elevation contour isolines. Multiple elevation raster lidar scans were taken from the Polish Geoportal open-access database and imported into ArcGIS. The mosaic method was then used to combine these files, creating a seamless raster elevation map. This map was then transformed into isolines using the "contour" function, with the contour line interval set at 0.5m. The resulting dataset was exported as a .dwg file and imported into Rhinoceros 7 software. Using the "extractPT" function on the set of isolines resulted in acquiring a dense point cloud, which later was transferred into a highly accurate NURBS-curve terrain model using “patch” and applying a high stiffness value. Generated terrain model was compared to the historical studies, exposing the traces of the former moat escarpment and remains of the trench that once covered the caponier.

6.1 Creation of 3D mesh model from Laser scanner point cloud

The authors aimed to achieve the highest level of precision, so they chose to initiate the reconstruction process using TLS and MLS point cloud data. To utilize this data in the computer graphics engine, the authors needed to convert the point cloud into a mesh through a technique called triangulation, which involves transforming a set of points, lines, or curves into a network of interconnected triangles or polygons. To refine the point cloud and minimize noise, certain cleaning functions in the open-source software "CloudCompare" were used. The "Poisson Reconstruction" function in the same software facilitated the automatic generation of a precise mesh, with the Octree depth set at 12 and scalar field density output. The resulting mesh was coloured based on the meta-information contained in the point cloud's points.

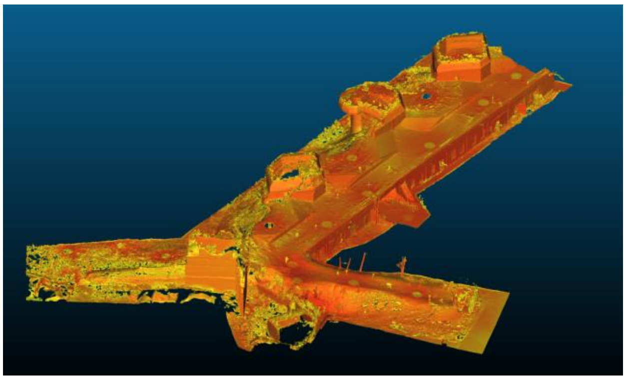


Figure 9. Mesh model based on laser scan generated using CloudCompare software.

To ensure the optimal output of the cloud meshing function's script, it was necessary to apply a scalar field filter to separate the excess mesh faces, resulting in a precise and distinct mesh suitable for subsequent processing (Nocerino, et al. 2020). The final mesh contained 28,288,693 triangular faces after trimming. Upon import into Rhinoceros 7, any unconnected elements were removed, and the "fill mesh holes" function was applied to acquire better watertightness.

6.2 Digital reconstruction of Port Battery

The digital reconstruction phase started with the alignment of different data sources, such as terrain models, mesh laser scans and historical sources in 3D software (Tucci, et al., 2019). The correct alignment was necessary for archiving the goal. Using the 3d modelling technique based on the Nurbs Curves (a type of mathematical representation of curves and surfaces based on the use of control points and mathematical formulas to generate smooth curves and surfaces) to acquire the highest precision and editing possibilities (Stathopoulou, et al., 2019). The reconstruction was based on previous research, and historical studies carried out by Robert Hirsch and Arkadiusz Woźniakowski (Hirsch 1995, 1996; Woźniakowski, Hirsch, 2023). All the 3d geometry supplemented to the mesh model were closed solid poly-surfaces to allow for further application of 3D printing techniques and non-problematic processing in game engines. To diversify the preserved this day part of the fortification with high-accuracy representation using a mesh model, the rest of the model was represented in simplified shapes and textures.

Figure 10. Mapping scheme of Port Battery. Green - Preserved and scanned part, Red - Phase 1, Blue - Phase 2.

Figure 11. Virtual reconstruction of the Port Battery around the year 1890, with the visual supplementation of missing elements, showing the whole complex.

Figure 12. Immersive VR application of the research outcome with live preview.

6.3 Virtual Reality Application

To achieve the final goal of incorporating Virtual Reality into their research (Galdieri, Carrozzino, 2019), the authors utilized the Oculus Quest 2 head-mounted display goggles connected to the PC workstation via Oculus Link Cable. To visualize the model in an immersive environment, the Enscape visualizing plugin was used, which eliminated the need to use a separate 3D environment and allowed for direct visualization from the 3D modelling software. While the Unity and Unreal Engines were considered, the authors found the Enscape software to be more user-friendly and satisfying for their research purposes. However, the further plans are to cover further processing of the model and its adaptation to different Virtual Reality solutions, such as CAVE (Mazikowski, 2014), based at the Immersive Visualization Lab at the Gdańsk University of Technology in another article, where the Unity engine serves as the main VR environmental engine. VR technology offers a significant advantage in the field of heritage, as it enables the creation of immersive experiences that replicate historical sites and objects in their complete and flourishing state, even if the original is incomplete or damaged. Moreover, VR can enhance accessibility (Chong et al. 2021) to heritage sites by providing virtual experiences that accurately represent the historical site or object, allowing individuals to have meaningful and educational experiences without physically visiting the site. This immersive and entertaining approach to Cultural Heritage can promote a deeper understanding and appreciation of history and former architecture, making VR technology a valuable tool for heritage preservation and sharing (Ferdani, et al., 2020).

Virtual reality can be a powerful tool in terms of academic didactics, regarding historical architecture and heritage conservation issues (Kowalski 2020a, 2020b), creating a representative group of heritage objects displayed in VR can be helpful in terms of fully understanding the architecture and conducting a thorough sightseeing tour in an immersive and interactive experience, VR can enable students to explore and study historical architecture in a way that would not be possible through traditional methods.

We are witnessing a growing number of VR applications that are increasingly being used in museology shifting the physical expositional spaces into much more intangible, immersive narrative applications (Pietroni, 2014; Pletinckx, 2003). However, the original substance, and materiality of heritage, including its authenticity and context, remains the most valuable aspect of built heritage. VR should not replace physical objects or sites but can be used to complement them and provide additional layers of interpretation and interactivity. A balance between technology and preservation must be maintained, and VR should be seen as a supplement to, not a replacement for, physical exhibitions (Selmanović, et al., 2020).

Using a specific 3D modelling methodology during the reconstruction phase enables the application of research findings for various uses, including 3D printing. A closed solid polysurface-based model can be created to produce scaled reconstructions, with potential uses that differ from those of VR. Additionally, a simple 3D model, visualized without VR solutions, can serve as a valuable educational tool. For instance, it can highlight the preserved and missing parts of the heritage site, without the need to immerse, for example by publishing models in online accessed sites allowing for interaction such as rotating and tilting the models like Sketchfab.

7. CONCLUSION

Although the research uses already established methodologies and tools, it is applied to a case study that has never been digitally documented before. The research, from the analysis of historical sources via the digital acquisition of the built environment to the post-production processes of the data, allowed a virtual reconstruction of the once integral fortification structure, enabling the understanding and visualisation of the historical changes. With the help of modern surveying tools and apertures such as terrestrial or mobile laser scanners, drones, etc. in conjunction with meshification, photogrammetry or GIS-based solutions it is possible to acquire very accurate databases. With the supplementation of historical research and sources, it is possible to create an intangible scientific reconstruction of objects of heritage using the 3d modelling technique. The products obtained so far suggest the broader potential of the research. The digital model created in such a matter can serve as a valuable tool to create open-air museological solutions for heritage objects that are incomplete, altered, destroyed, or complex, using modern technologies such as virtual reality. It can be used to educate and engage interested viewers with the heritage site uniquely and interactively, offering a new perspective on the past.

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REFERENCES

Acampa, G., Grasso, M., 2020. Heritage Evaluation: restoration plan through HBIM and MCDA. IOP Conference Series. Materials Science and Engineering, 949(1), 012061. https://doi.org/10.1088/1757-899x/949/1/012061

Amado, M., Lourenço, P. B., Peña, F., 2009. Virtual reconstruction of medieval monastery using computer-aided design model. Journal of Architectural Engineering, 15(4), 131–138. https://doi.org/10.1061/(asce)1076-0431(2009)15:4(131)

Arbace, L., Sonnino, E., Callieri, M., Dellepiane, M., Fabbri, M., Iaccarino Idelson, A., Scopigno, R., 2013. Innovative uses of 3D digital technologies to assist the restoration of a fragmented terracotta statue. Journal of Cultural Heritage, 14(4), 332–345. https://doi.org/10.1016/j.culher.2012.06.008

Checa, D., Miguel-Alonso, I., & Bustillo, A., 2021. Immersive virtual-reality computer-assembly serious game to enhance autonomous learning. Virtual Reality. https://doi.org/10.1007/s10055-021-00607-1

Chong, H. T., Lim, C. K., Ahmed, M. F., Tan, K. L., Mokhtar, M. B., 2021. Virtual reality usability and accessibility for cultural heritage practices: Challenges mapping and recommendations. Electronics, 10(12), 1430. https://doi.org/10.3390/electronics10121430

Dell'Amico, A., 2021. Mobile laser scanner mapping system's for the efficiency of the survey and representation processes, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-M-1-2021,199–205,https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-199-2021
De Marco, R., Pettineo, A., 2022. The recognition of heritage qualities from feature-based digital procedures in the analysis of historical urban context, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-2/W1-2022,175–182, https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-175-2022

Doria, E., Galasso, F., Morandotti, M., 2022. Heritage documentation and management processes: Castiglioni Chapel in Pavia. Acta IMEKO, 11(1). https://doi.org/10.21014/acta_imeko.v11i1.1086

Doria, E., Fu, H., Picchio, F., 2023. Digital Reconstruction for the Analysis of Conservation State: The Transmission of Historical Memory of St. George and the Dragon Tile in San Michele Basilica Facade. In Trizio I., Demetrescu, E., Ferdani, D., (eds. by) *Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage*. Vol. pp. 151-167. Cham: Springer International Publishing.

Bruno, F., Bruno, S., De Sensi, G., Luchi, M.-L., Mancuso, S., & Muzzupappa, M., 2010. From 3D reconstruction to virtual reality: A complete methodology for digital archaeological exhibition. Journal of Cultural Heritage, 11(1), 42–49. https://doi.org/10.1016/j.culher.2009.02.006

Ferdani, D., Fanini, B., Piccioli, M. C., Carboni, F., Vigliarolo, P. 2020. 3D reconstruction and validation of historical background for immersive VR applications and games: The case study of the Forum of Augustus in Rome. Journal of Cultural Heritage, 43, 129-143. https://doi.org/10.1016/j.culher.2019.12.004

Galdieri, R., Carrozzino, M., 2019. Natural Interaction in Virtual Reality for Cultural Heritage. In: Duguleană, M., Carrozzino, M., Gams, M., Tanea, I. (eds. by) VR Technologies in Cultural Heritage. VRTCH 2018. Communications in Computer and Information Science, vol 904. Springer, Cham. https://doi.org/10.1007/978-3-030-05819-7_10

Hirsch, R. (1995). Bateria Portowa w Gdańsku - historia i stan obecny. Infort, Biuletyn Miłośników Fortyfikacji (Gdańsk), 9, 7-12.

Hirsch, R. 1996. Bateria Nadmorska. Spotkania z zabytkami 20(3), 22-23.

Jokilehto, J., 2007. History of Architectural Conservation. Routledge.

Kowalski, S. , Samól, P. , Szczepański, J., Dłubakowski, W., 2020. Teaching architectural history through virtual reality. World Transactions on Engineering and Technology Education, 18(2), 197–202.

Kowalski, S, Samól, P., Hirsch, R., 2020. Virtual reality tools in teaching the conservation and history of Polish architecture. Teaching architectural history through virtual reality. World Transactions on Engineering and Technology Education, 18(4), 399–404.

Kowalski, S., Samól, P., Szczepański, J., 2023. Physical models in the education of architectural history. World Transactions on Engineering and Technology Education, 20(4), 251–257.

Landrieu, J., Père, C., Rollier, J., Castandet, S., Schotte G., 2012. Digital rebirth of the greatest church of cluny maior ecclesia:from optronic surveys to real time use of the digital mode. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XXXVIII-5/W16,31–37,https://doi.org/10.5194/isprsarchives-XXXVIII-5-W16-31-2011.

Mazikowski, A., Lebiedź, J., 2014. Image projection in immersive 3D visualization laboratory. Procedia Computer Science, 35, 842–850. https://doi.org/10.1016/j.procs.2014.08.251

Nocerino, E., Stathopoulou, E. K., Rigon, S., Remondino, F., 2020. Surface reconstruction assessment in photogrammetric applications. Sensors, 20(20), 5863. https://doi.org/10.3390/s20205863

Parrinello, S., Bertacchi, S., 2014. The Fort of Bernia by Giovanni Battista Antonelli. Nexus Netw J 16, 699–722. https://doi.org/10.1007/s00004-014-0214-8

Parrinello, S.; Picchio, F., 2015. The complex of San Lorenzo del Chagres in Panama: historical development and survey project for the documentation of the Caribbean fortress. En Defensive architecture of the mediterranean: XV to XVIII centuries. Vol. II. Editorial Universitat Politècnica de València. 265-272. https://doi.org/10.4995/FORTMED2015.2015.1771

Parrinello, S., Picchio, F., De Marco, R., Dell’Amico, A., 2019. Documenting the cultural heritage routes. the creation of informative models of historical russian churches on upper kama regione, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W15, 887–894, https://doi.org/10.5194/isprs-archives-XLII-2-W15-887-2019.

Parrinello, S., Picchio, F., 2019. Integration and comparison of close-range sfm methodologies for the analysis and the development of the historical city center of bethlehem. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 42, 589-595. https://doi.org/10.5194/isprs-archives-XLII-2-W9-589-2019

Parrinello, S., Dell’Amico, A., 2019. Experience of documentation for the accessibility of widespread cultural heritage. Heritage 2 (1), pp. 1032-1044. https://doi.org/10.3390/heritage2010067

Parrinello, S., Cioli, F., 2020. Establishment of a Complex Database for the Study of Cultural Heritage Through the Reading and Analysis of the Traditional Architecture of Upper Kama. In: Kremers, H. (eds) Digital Cultural Heritage. Springer, Cham. https://doi.org/10.1007/978-3-030-15200-0_4

Parrinello, S., Picchio, F., Dell’amico, A., Malusardi, C., 2020. Le mura di Cartagena de Indias tra sperimentazione metodologica e protocolli operativi. Strumentazioni digitali a confronto per lo studio del sistema difensivo antonelliano. Editorial Universitat Politècnica de València. 415-422. https://doi.org/10.4995/FORTMED2020.2020.11393

Parrinello, S., De Marco, R., 2021. Digital surveying and 3D modelling structural shape pipelines for instability monitoring in historical buildings: a strategy of versatile mesh models for ruined and endangered heritage. Acta IMEKO, 10(1), 84-97.DOI: https://doi.org/10.21014/acta_imeko.v10i1.895

Picchio, F., Pettineo, A. 2023. Digitalizzare, ricostruire e fruire il Castello di Montorio: un tassello nella definizione della rotta culturale dei castelli scaligeri. In Bevilacqua M., G., Ulvieri, D., (ed. by) *Defensive architecture of the mediterranean Vol.XV*, pp. 1123-1130, Pisa: PisaUniversity Press.

Pierdicca, R., Frontoni, E., Malinverni, E. S., Colosi, F., & Orazi, R. (2016). Virtual reconstruction of archaeological heritage using a combination of photogrammetric techniques: Huaca Arco Iris, Chan Chan, Peru. Digital Applications in Archaeology and Cultural Heritage, 3(3), 80–90. https://doi.org/10.1016/j.daach.2016.06.002

Pietroni, E., Adami, A. (2014). Interacting with virtual reconstructions in museums: The Etruscanning project. Journal on Computing and Cultural Heritage, 7(2), 1–29. https://doi.org/10.1145/2611375

Pletinckx, D., Silberman, N., & Callebaut, D. (2003). Heritage presentation through interactive storytelling: a new multimedia database approach. Journal of Visualization and Computer Animation, 14(4), 225–231. https://doi.org/10.1002/vis.319

Remondino, F. (2011). Heritage recording and 3D modeling with photogrammetry and 3D scanning. Remote Sensing, 3(6), 1104–1138. https://doi.org/10.3390/rs3061104

Sammartano, G., Spanò, A., 2018. Point clouds by SLAM-based mobile mapping systems: accuracy and geometric content validation in multisensor survey and stand-alone acquisition. Appl Geomat 10, 317–339. https://doi.org/10.1007/s12518-018-0221-7

Samól, P., Hirsch, R., & Woźniakowski, A., 2022. Wieniec w Twierdzy Wisłoujście z lat sześćdziesiątych XVI wieku, jego przekształcenia i uszkodzenie w wojnie w roku 1577 w świetle badań architektonicznych z lat 2020–2022. Wiadomości Konserwatorskie - Pismo Stowarzyszenia Konserwatorów Zabytków, 72, 62-79. https://doi.org/10.48234/wk72wreath

Samól, P., Hirsch, R., & Woźniakowski, A., 2021. Dzieje latarni w Twierdzy Wisłoujście w świetle badań architektonicznych z roku 2018 History of the Lighthouse of the Wisłoujście Fortress in Light of a 2018 Architectural Study. Wiadomości Konserwatorskie - Pismo Stowarzyszenia Konserwatorów Zabytków, 21-36. https://doi.org/10.48234/wk66lighthouse

Samól, W., Kowalski, S., Woźniakowski, A., & Samól, P., 2023. Where the Second World War in Europe broke out: The landscape history of Westerplatte, Gdańsk/Danzig. Land, 12(3), 596. https://doi.org/10.3390/land12030596

Selmanović, E., Rizvic, S., Harvey, C., Boskovic, D., Hulusic, V., Chahin, M., Sljivo, S., 2020. Improving accessibility to intangible cultural heritage preservation using virtual reality. Journal on Computing and Cultural Heritage (JOCCH), 13(2), 1-19. https://doi.org/10.1145/3377143

Stathopoulou, E.-K., Welponer, M., and Remondino, F., 2019. Open-source image-based 3d reconstruction pipelines: review, comparison and evaluation, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W17, 331–338, https://doi.org/10.5194/isprs-archives-XLII-2-W17-331-2019

Tucci, G., Rihal, S., Betti, M., Conti, A., Fiorini, L., Kovacevic, V. C., and Bartoli, G.: Ground based 3D modelling photogrammetry and tls) survey, documentation and structural assessment of XX century cultural heritage in India - A case study of the masonry vaults in Dehradun, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W11, 1105–1111,https://doi.org/10.5194/isprs-archives-XLII-2-W11-1105-2019

Woźniakowski, A., Hirsch R. (2023). Studies of 19th century defensive architecture using traditional and digital research methods on the examples of coastal fortifications in Poland. Architectus (in print), originally presented at the ArchReSci conference, 23-25 March 2023