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 neglect 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. 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).

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.

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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 not to 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.

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.

5. POSTPRODUCTION OF ACQUIRED DATA

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

Figure 6. TLS scan position and MLS path.
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.

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.

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

Figure 8. Port Battery point cloud database.

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

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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