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Fortresses and military architecture in the City of Gdańsk

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Side page, Fig. 01
Remains of Port Battery.

Amidst the realm of architectural heritage structures, fortifications present a distinctive challenge owing to their inherent and specific functionality, rendering them resistant to alterations and susceptible to potential neglect and decay. Their existence also introduces difficulties related to preservation, maintenance, public safety, and accessibility. In accordance with heritage conservation principles[1] and recognizing the outdated nature of their function, physically reconstructing fortifications may be deemed unnecessary. Consequently, the essence of experiencing these integral heritage objects can be captured through digital tools[2]. In the pursuit of initiating actions for enhancement and valorization, this research centers on implementing an operational workflow geared towards rediscovering military heritage using the potential offered by digital technologies. The investigative process entails integrating various survey methodologies to attain the most comprehensive and detailed understanding of the heritage artifact[3].

The research unfolds in three distinct methodological steps: an initial phase of historical analysis, a subsequent phase involving a digital survey of the current structure, and a final phase in which a 3D model is developed to compare historical sources with contemporary data. This contribution specifically delves into the second and third phases, elucidating the methodology and outcomes of digital survey activities.

State of art

Nowadays, the Port Battery stands as a distinctive ruin, visible from the cliffs that stretches along the Baltic Sea coast in Gdańsk. Situated within the protected precincts of Gdańsk's Port's free customs area, the Battery owes its relatively well-preserved state to the restricted access that shielded it from theft and vandalism. Unfortunately, the battery itself bears substantial damage, a consequence of insufficient conservation efforts and shortsighted actions by the seaport.

These actions were geared towards accommodating communication needs for trucks operating on the quays, leading to further deterioration and the dismantling of remnants from the original fortification.

[1] Jokilehto (2007), *History of Architectural Conservation.*
[2] Pierdicca et al. (2016), *Virtual reconstruction of archaeological heritage using a combination of photogrammetric techniques: Huaca Arco Iris, Chan Chan, Peru.*
[3] Parrinello et al. (2019), *Documenting the cultural heritage routes. The creation of informative models of historical Russian churches on upper Kama region.*

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Fig. 02
Remains of Port Battery

Regrettably, this has left the battery with a rather impaired appearance[4].

Positioned within a confined and regulated seaport zone, the survey of the Port Battery had to be executed swiftly to avoid disruption to dockworker activities. In response, the authors undertook a comprehensive examination of the battery and its surroundings, leveraging mobile equipment that facilitated the completion of the survey and data acquisition within a single working day. Preceding the survey, the team meticulously evaluated methods and acquisition strategies for each mobile device, as well as for GPS and TLS instrumentation. These measures were crucial in ensuring the metric reliability of the digital product[5].

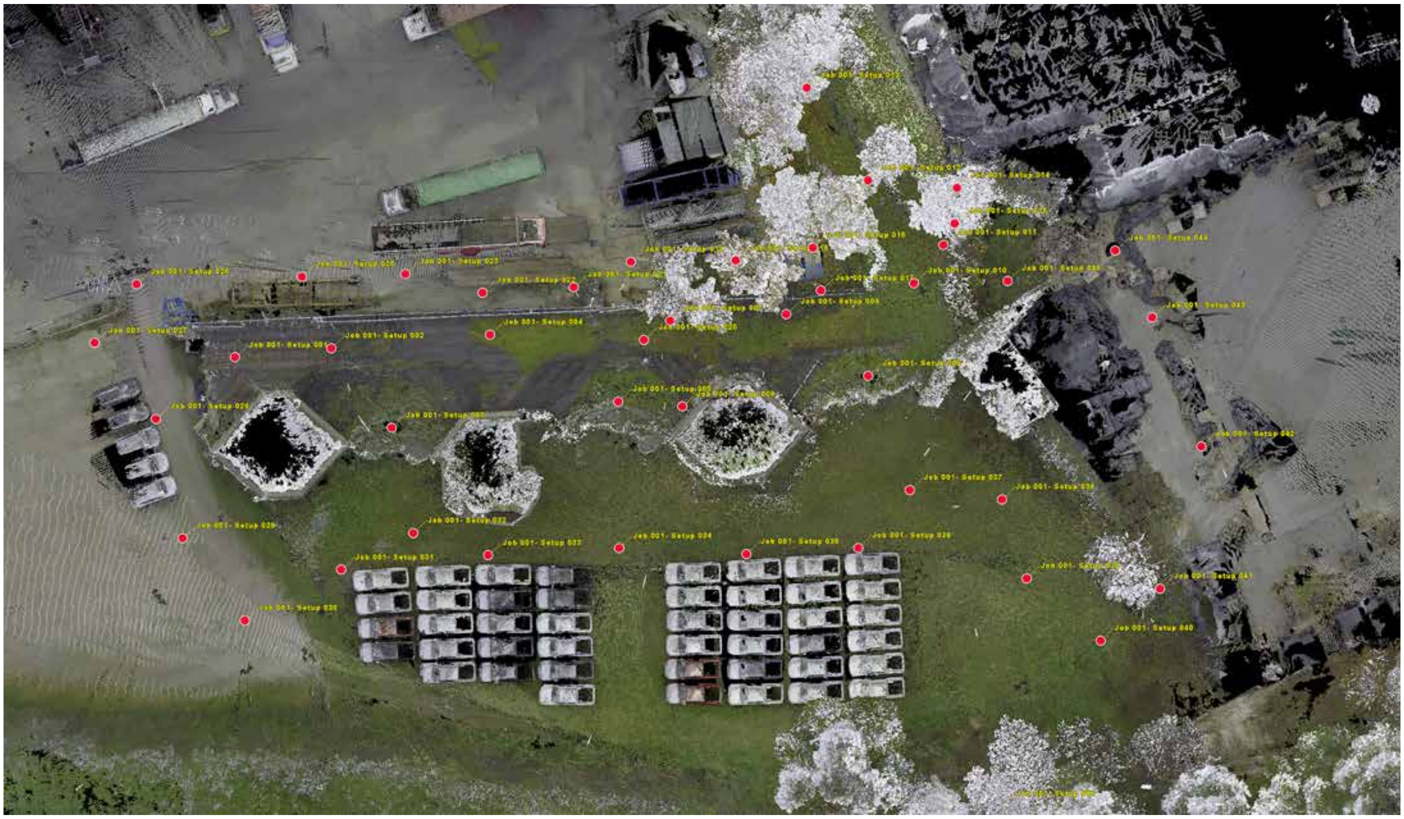
Digital acquisition of Port Battery

The Port Battery and its surroundings underwent their inaugural digital survey, utilizing a range of instruments to swiftly compile a comprehensive documentation of the area. The TLS LiDAR (RTC360) acquisition campaign focused on documenting the external walls and surroundings of the structure. Following a polygonal path parallel to the outer walls, the operator executed 49 scans. The use of polygonal paths played a crucial role in minimizing and compensating for metric errors during post-production alignment (max. error: 1-2 cm). Interior surveying employed MLS LiDAR (BLK2GO), with the operator completing 7 closed paths, overlapping one another at an average distance of 2 meters from architectural surfaces[6]. These paths originated from outside the battery to ensure the acquisition of morphological points necessary for integrating TLS data. To georeference the dataset, a topo-

[4] Hirsch (1995), *Bateria Portowa w Gdańsku - historia i stan obecny*, pp. 7-12; Hirsch (1996), *Bateria Nadmorska*, pp. 22-23;Woźniakowski, Hirsch (2023), *Studies of 19th Cen.tury defensive architecture using traditional and digital research methods on the examples of coastal fortifications in Poland*.

[5] Picchio, Pettineo (2023), *Digitalizzare, ricostruire e fruire il Castello di Montorio: un tassello nella definizione della rotta culturale dei castelli scaligeri*, pp. 1123-1130.

[6] Dell'Amico (2021), *Mobile laser scanner mapping system's for the efficiency of the survey and representation processes*, pp. 199-205.



graphic acquisition campaign was conducted using Leica Geosystem GNSS GS07 to acquire GPS point coordinates. These points were strategically placed along the battery's boundary and roof to establish a polygonal network, ensuring better control and error compensation. Due to area access restrictions, drone usage was prohibited, necessitating a ground-based approach for photogrammetric acquisition and processing operations[7]. Using photogrammetric techniques from the ground, operators captured 671 photographs with approximately 70% overlap between contiguous photos. The 24.2 MP full-frame Panasonic Lumix S5 mirrorless camera maintained a constant focal length of 20 mm during acquisition, resulting in a ground sample distance (GSD) below 0.02. The camera's large sensor facilitated enhanced light collection, contributing to increased image quality and aiding the software algorithm in constructing the 3D photogrammetric model[8]. The digital duplicate obtained revealed data gaps in certain coverage areas, which were partly addressed by integrating laser instrumentation data. However, challenges persisted, such as the degraded condition of some architectural portions (e.g., missing concrete covers for artillery positions in battery ruins) and substantial vegetation on the flat roof and access ramps. The data from the acquisition phase underwent processing for individual datasets, eventually being integrated into a single global point cloud. Subsequently, post-production processes were initiated to define digital models of the Port Battery.

Fig. 03
Spatial Arrangement of Scan Positions on Terrestrial LiDAR Point Cloud visualized in Leica Cyclone Software

Fig. 04
Integration of TLS and MLS datasets

[7] Remondino (2011), *Heritage recording and 3D modeling with photogrammetry and 3D scanning.*
[8] Parrinello, Picchio (2015), *The complex of San Lorenzo del Chagres in Panama: historical development and survey project for the documentation of the Caribbean fortress.*

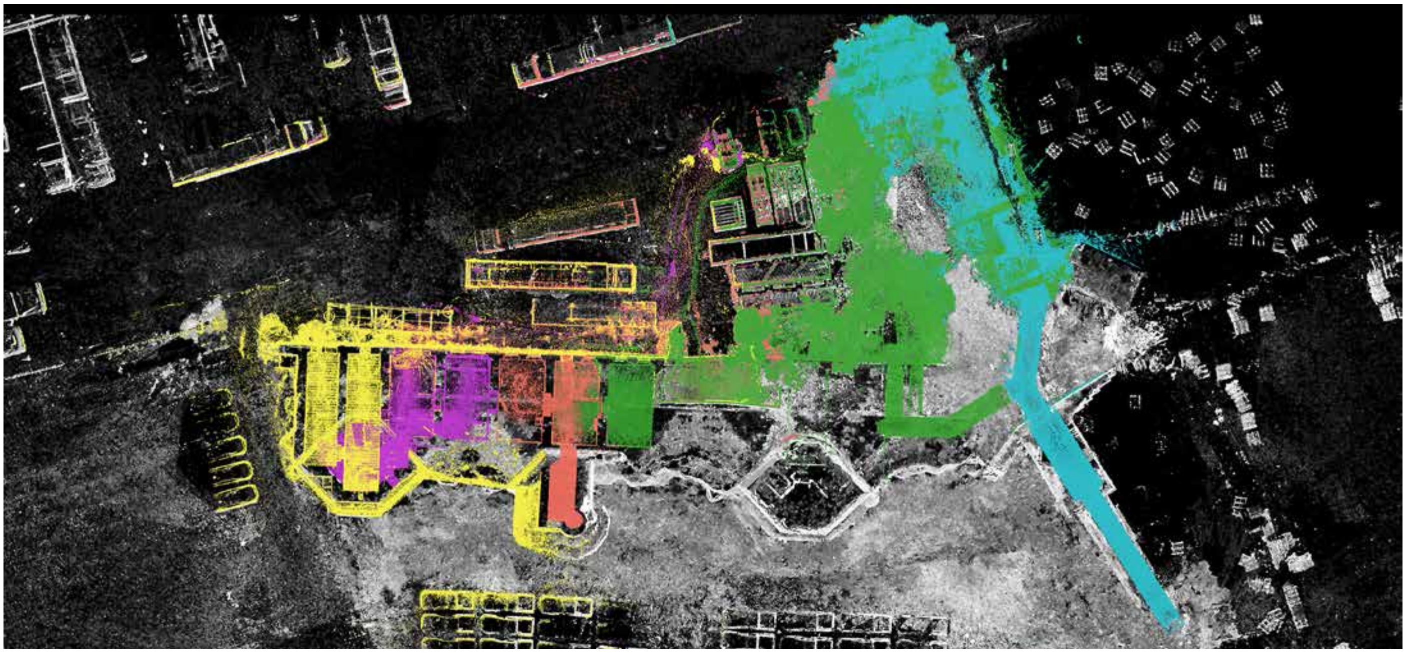


Fig. 05
Integration of TLS and MLS datasets. Interiors of battery

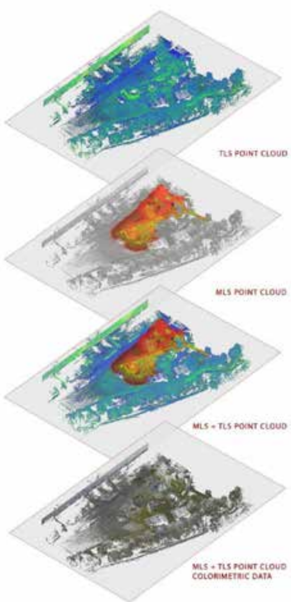


Fig. 05
Port Battery point cloud databases

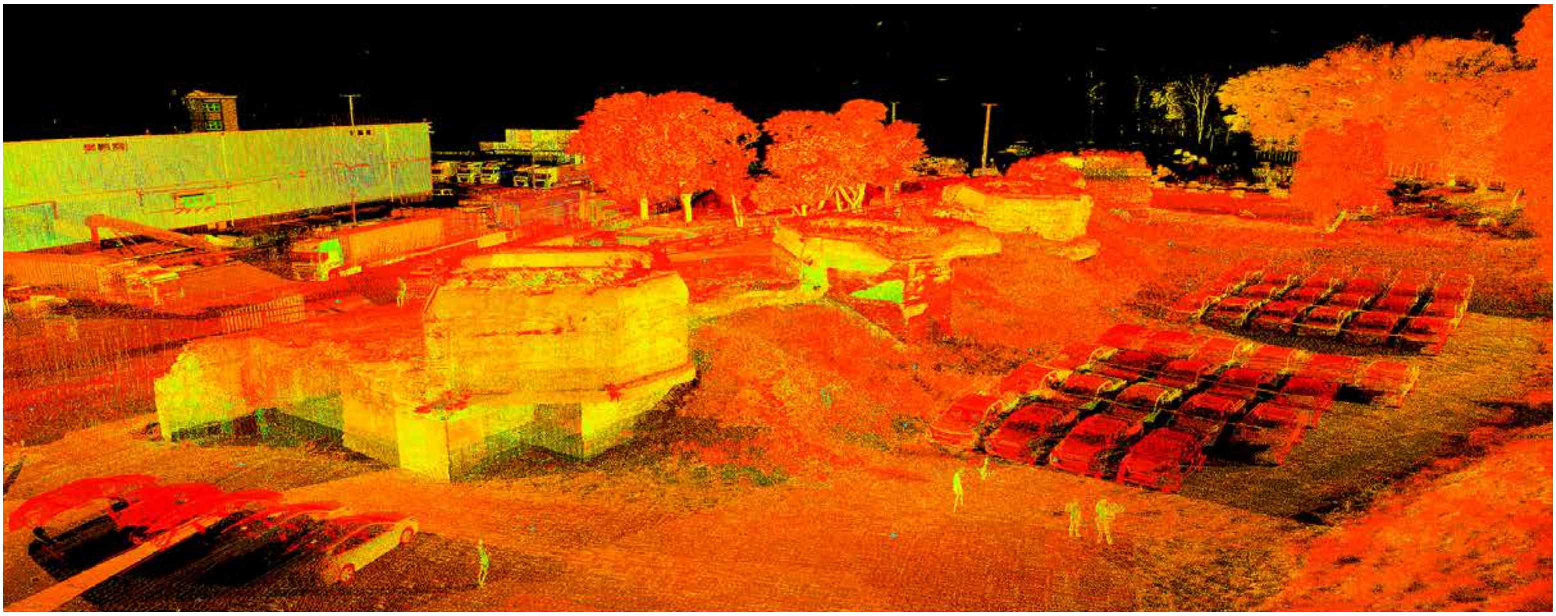
Fig. 06
Results of TLS and MLS point cloud registration, with different visualization filters (density, RGB), process in Leica Cyclone Software

Postproduction phase

The dataset underwent individual database processing based on the respective instrumentation (TLS and MLS). Following referencing through morphological points and cloud-to-cloud alignments using Leica Cyclone software, the point clouds from TLS and MLS datasets were seamlessly merged into a unified global point cloud. TLS scans, enriched with RGB data, provided detailed colorimetric information crucial for decay mapping and structural preservation evaluations[9]. In comparison, MLS exhibited a lower density—less than 2 million points/square meter—with accompanying RGB information. The MLS data displayed reasonable reliability compared to TLS, boasting average deviations of 3-10 cm at both architectural and detail levels.

Georeferencing of the integrated point cloud was accomplished using on-site GPS points. In Leica Cyclone software, the .txt coordinates of all points were imported as a point system, designating the position related to the GPS point as a vertex. This GPS coordinate point system served as the reference scan word ("homeword") for the registration alignment process. Consequently, all vertices within the point cloud were accurately "shifted" into the correct coordinate system, with an average deviation of 10-15 cm. It's important to note that the error obtained may be influenced by the chosen position/number of points and the instrumentation. The model used carried an average default error of 2-10 cm, compounded by potential inaccuracies in the instrument's bubble setting, manually performed by the operator. Subsequent to this georeferencing process, the acquired data underwent further processing to generate mesh models using the point cloud-to-mesh technique (Kowalski et al., 2023). These models were simplified and optimized to facilitate visualization in a 3D graphical engine, preparing the data for eventual 3D printing.

[9] Doria et al. (2022), *Heritage documentation and management processes: Castiglioni Chapel in Pavia.*



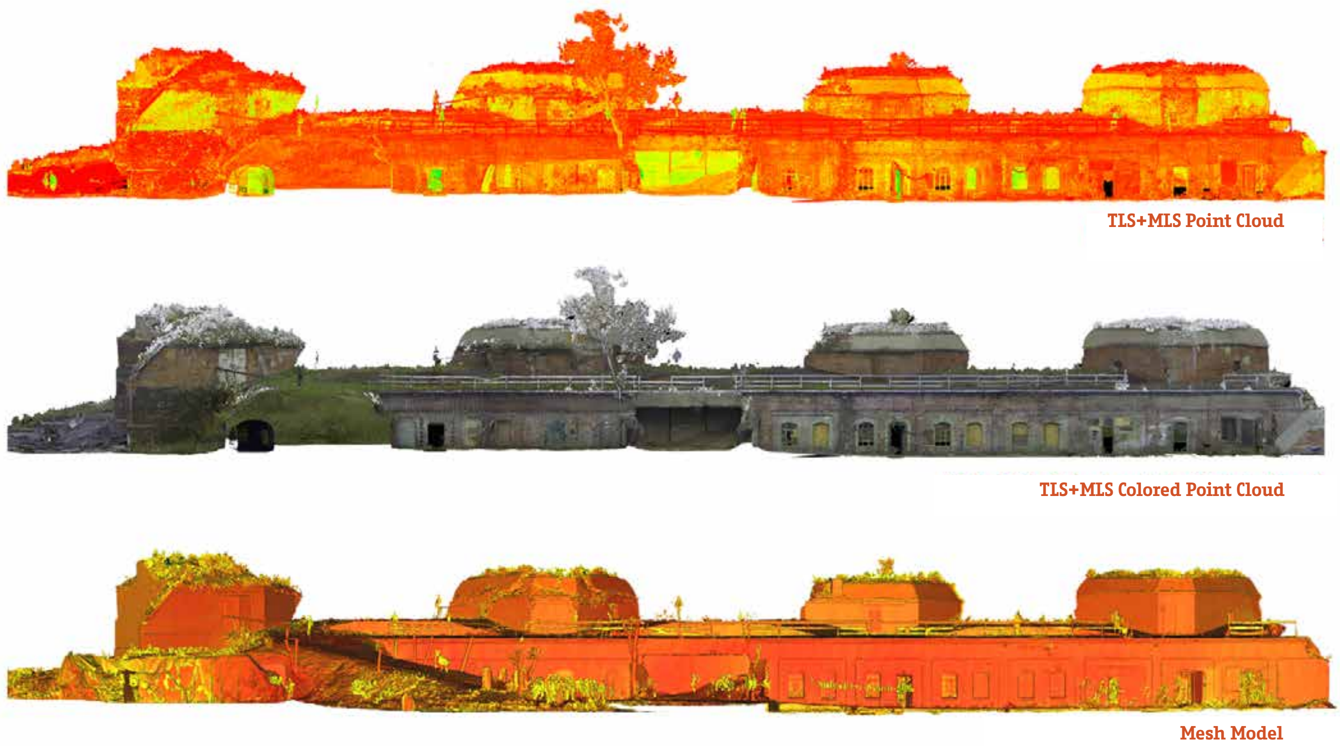


Fig. 07
Transformation of integrated scan to mesh model. Elevations of Port Battery Remains

3D Reconstruction based on historical sources

The initial step in digital reconstruction involved creating a terrain model. Lidar scans from the Polish Geoportal open-access database were imported into ArcGIS, and the mosaic method combined these scans to produce a seamless raster elevation map.

This map was then transformed into isolines using the "contour" function, with a contour line interval of 0.5m. The resulting dataset was exported as a .dwg file and imported into Rhinoceros 7 software. Utilizing the "extractPT" function on the isolines generated a dense point cloud, subsequently transformed into a highly accurate NURBS-curve terrain model using the "patch" function with a high stiffness value. The generated terrain model was compared to historical studies.

For achieving precision in architectural reconstruction, TLS and MLS point cloud data were utilized. The point cloud was converted into a mesh using the open-source software "CloudCompare."

The "Poisson Reconstruction" function in the same software automatically generated a mesh with an Octree depth set at 12 and scalar field density output. The resulting mesh was colored based on meta-information in the point cloud. A scalar field filter was applied to separate excess mesh faces, yielding a precise and distinct mesh suitable for further processing[10]. The final mesh, containing 28,288,693 triangular faces after trimming, was imported into Rhinoceros 7.

Unconnected elements were removed, and the "fill mesh holes" function was applied to ensure better watertightness. The data, terrain models, laser mesh scans, and historical sources, were then aligned in a single 3D software. Robert Hirsch and Arkadiusz Woźniakowski's research guided the historical reconstruction. To diversify the part of the actually preserved fortification (modeled based on

[10] Nocerino et al. (2020), *Surface reconstruction assessment in photogrammetric applications.*

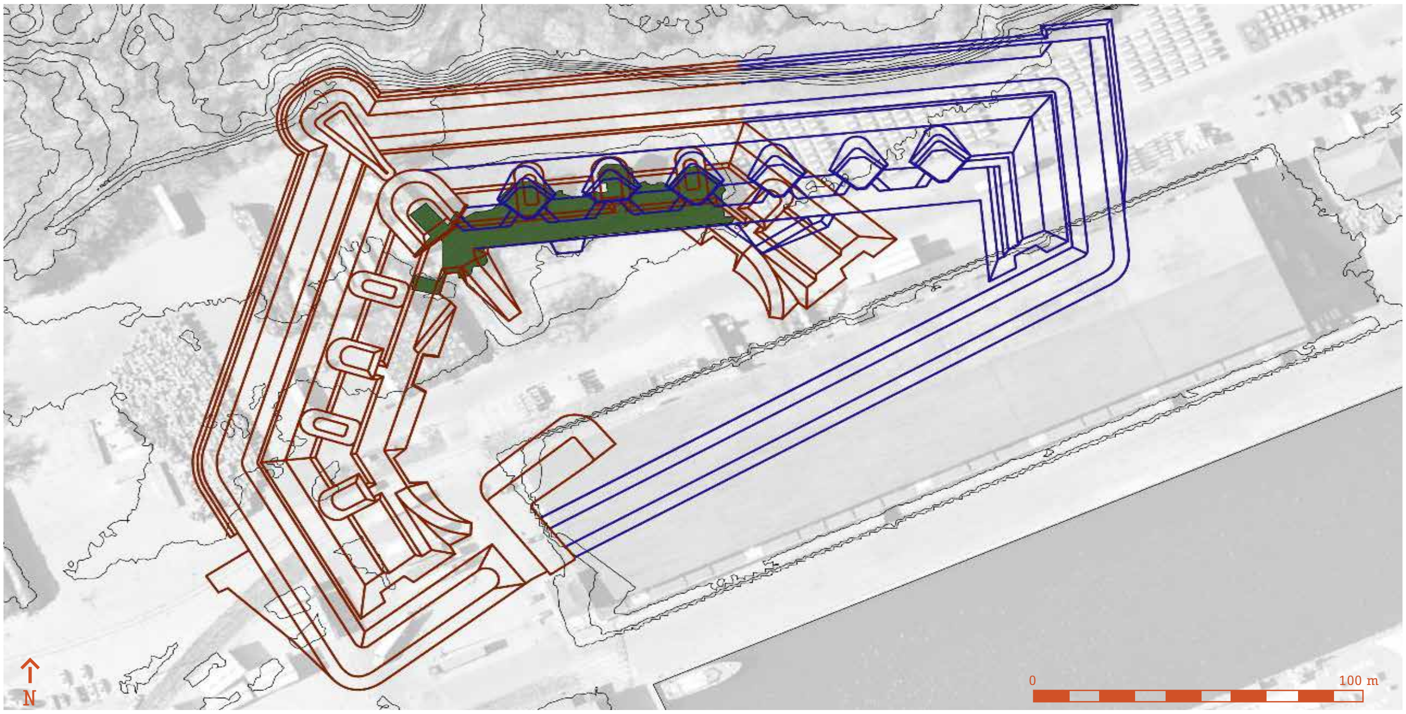


Fig. 08
Mapping scheme of Port Battery
Green - Preserved and scanned part, Red - Phase 1, Blue - Phase 2.

reality-based data in mesh) from the assumed one, the rest of the model was represented with simplified shapes and textures.

To integrate Virtual Reality (VR) into the research, Oculus head-mounted display glasses connected to a PC via Oculus Link cable were used. Enscape visualization plugin, chosen for its user-friendly nature compared to Unity and Unreal engines, facilitated immersive VR experiences. The VR immersive and entertaining approach to Cultural Heritage can promote a deeper understanding and appreciation of history and former architecture[11]. Virtual reality can be a powerful tool also in terms of academic didactics[12], enabling students to explore and study historical architecture in a way that would not be possible through traditional methods. However, VR complements physical objects and sites, offering additional layers of interpretation and interactivity, emphasizing its role as a supplement rather than a replacement for physical exhibitions[13]. The specific 3D modeling methodology used during the reconstruction phase enables also the application of research findings for various uses. A digital closed solid polysurface-based model can be in fact created to produce scaled reconstructions, with potential uses that differ from those of VR.

For instance, it can highlight the preserved and missing parts of the heritage site, for example by

[11] Ferdani et al. (2020), *3D reconstruction and validation of historical background for immersive VR applications and games: The case study of the Forum of Augustus in Rome*.
[12] Kowalski et al. (2020), *Teaching architectural history through virtual reality, in World Transactions on Engineering and Technology Education*.
[13] Selmanović et al. (2020), *Improving accessibility to intangible cultural heritage preservation using virtual reality, in Journal on Computing and Cultural Heritage.*

Fig. 09
Digital scann based reconstruction of remaining elements of Port Battery

publishing models in online accessed sites allowing for interaction, like Sketchfab; or it can be 3D printed, enabling a physical didactic use. 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. 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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Fig. 10
Digital reconstruction in Virtual Reality enviroment with Oculus Quest 2 headset

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