Digital Tools for Interpretation of Reconstructed Mining Features. Project Digital Geopark Muskau Arch

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Keywords: 3D models, virtual tour, augmented reality, geoportal, post-mining heritage.

Abstract

The bilateral UNESCO Geopark Muskau Arch, located on the German-Polish border is characterized by a unique glaciotectonic post-mining landscape where most evidence of former industrial activity has been removed or concealed due to man-made and natural revitalization processes. This paper presents a strategy and pilot works for digitally reconstructing and presenting the forgotten mining heritage of the geopark using advanced geospatial and geovisualisation technologies such as 3D point cloud based modelling, Augmented Reality (AR) tools and proprietary generative Artificial Intelligence algorithms. The project, developed under the Poland-Saxony INTERREG 2021–2027 programme, integrates archival materials with field-acquired data to produce accurate 3D models of key heritage objects, including underground mining workings, shaft heads, transport infrastructure, and industrial buildings. These digital reconstructions including textures and descriptive information will be used to present in an attractive and interactive ways including augmented reality mobile application, virtual tours with 360 degree panoramas and will be embedded within a geoportal featuring interactive maps. Preliminary results of reconstructing selected mining objects demonstrate the feasibility of combining photogrammetric surveys, laser scanning, archival photographs, plans, and historical mining maps to create hybrid 3D models that accurately represent the character and dimensions of vanished structures, supporting heritage education and preservation for diverse user groups such as tourists, pupils, and local community.

1. Introduction

Digital visualisation technologies such as 360° panoramas, virtual tours, virtual and augmented reality applications, geoportals or interactive story maps have been successfully applied to present various forms of natural and man-made heritage around the world (Kuna and Kowalski, 2020; Liu et al., 2024). However, the selection of approach that will meet the specific purpose requires careful analysis of the context of heritage site characteristics, location, data acquisition options and the intended target groups. This issue is particularly significant when original features that once defined the character of a site are no longer present due their dismantling, reworking or covering by contemporary development. This is often the case of post- mining sites (Szymanski, 2010) and results in history of a place being no longer accessible.

The aim of this study is to develop and test a strategy for the digital reconstruction and presentation of forgotten heritage associated with both underground and open-pit mining activities formerly conducted within the present-day transboundary UNESCO Global Geoparks site, Muskau Arch Geopark, located on the border between Germany and Poland

The research is led by scientific partners from Poland (Wroclaw University of Science and Technology) and Germany (Freiberg Technical University) in cooperation with the European Grouping of Territorial Cooperation - EGTC Geopark Muskau Arch within the project “Digital Journey through Geopark Muskau Arch” co-financed from the European Regional Development Fund as part of the Poland-Saxony 2021-2027 INTERREG Cooperation Program. The project started in the 1st half of 2025 and will conclude in the 1st half of 2028 when the developed digital product will be made available for the general public (https://digitalgeopark.pwr.edu.pl/en).

The specific aims of the project include: (1) identification and inventorying of representative historical underground and surface mining objects in Polish and German parts of the Geopark using available archival mining maps and plans, written documentations and preserved photographs, (2) collection of photogrammetric and point cloud field data in the study area for digital reconstructions of remains of mining-related objects, (3) digital reconstruction of selected mining and geology-related objects in 3D optimized for mobile augmented reality (AR) application, taking into account constraints such as model complexity, level of detail (LOD), and real-time rendering performance, (4) design and implementation of a georeferenced framework for integrating 3D models into a mobile AR environment, ensuring accurate spatial alignment with the contemporary landscape, (5) preparation of multimedia content (such as textures, descriptions, and metadata) to enhance user interaction and interpretation within the AR application, (6) development of an integrated geoportal-based platform for presenting reconstructed heritage using interactive maps, 360° panoramas, and virtual tours, and (7) evaluation of the potential of digital tools, including augmented reality, for enhancing the accessibility and interpretation of mining heritage that is no longer visible in the contemporary landscape, as well as assessment of the role of digital reconstruction in preserving and promoting post-mining cultural and natural heritage within transboundary protected areas. In this paper preliminary results of the first three tasks have been presented.

https://doi.org/10.5194/isprs-archives-XLIX-B4-2026-229-2026

2. Study Area

The UNESCO Geopark Muskau Arch is associated with push moraine of the same name. It was originally formed during the Elsterian (MOIS 12) glaciation and was remodelled during successive glacial periods (Kupetz, 1997). The multi-staged evolution of glacial landforms in the area led to folding, upthrust and subsequent erosion of initially lower lying and covered deposits including brown coal deposits (Urbański, 2007). The oldest ice-sheet advance in the Elsterian produced three main parallel arcs of push moraines. Next, the older Saalian ice sheet (MOIS 6) deeply eroded and truncated most of the elevated parts. Further denudation by non-glacial processes gave the area its complex appearance (Koźma and Migoń, 2024). This, original, landscape was then permanently transformed during underground and open-pit mining of predominately brown coal deposits, as well as clay and sand raw materials. Exposed and shallow lying brown coal deposits contributed to the beginning of coal mining in the western part of the Muskau Arch as early as 1843. This industrial activity lasted until early 70’ties of the 20th century in the easter part. A photograph of the largest brown coal open-pit from the 60’ties is shown in Photo 1.

Figure 1. Part of the open-pit in the “Przyjaźń Narodów - Szyb Babina” mine ca. 1964-1967 (photo by Cz. Luniewicz, source: National Archive in Zielona Gora, Poland)

Subsequent, planned followed by natural, reclamation processes led to the creation of new lake and forest landscape. In recent years, tourist development of this unique glaciotectonic post-mining site has significantly increased (Koźma and Migoń, 2024), including the establishment of educational trails, information points, viewing tower, etc. However, during the time that elapsed since the end of mining activity (1970’s) most of the industrial objects and features associated with former industrial operations (e.g. glass and ceramic production) have been removed, destroyed or changed by new development and the knowledge about the industrial past is slowly disappearing. Local authorities and communities on both sides of the border have been actively working to preserve the identity (*genius loci*) of the place. Thus, there is a need to develop a coordinated bilateral strategy that ensures the sustainable protection, reconstruction, and presentation of the region’s mining heritage for present and future generations. Digital technologies can serve a key role in addressing this gap by enabling precise and durable documentation, visualization, and interactive engagement with the region’s post-mining heritage features. The contemporary view of the former open-pit from Figure 1 is shown in Figure 2.

Figure 2. Aerial view of the part of post-mining lake (2025) (photo by M. Becker, source: National Science Centre project no 2021/43/B/ST10/02157)

The location of the moraine (brown colour) and generalised extent of the UNESCO bilateral Geopark (green colour) on the German-Polish border are presented in Figure 3.

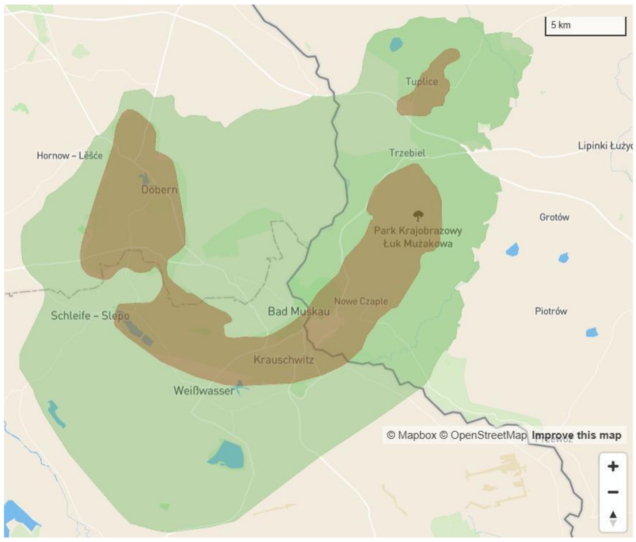

Figure 3. Location of the Geopark Muskau Arch (source: EGTC, 2025)

3. Materials and Methods

In the first stage of our study, the desk research methodology that involved the systematic collection, review, and analysis of existing materials, was implemented. Available materials documenting the industrial past were obtained from national public sources, such as the State Mining Authority, and regional state archives, local communities, and academic institutions. The acquired documentations included: archival topographic maps, mining plans, preserved photographs, historical documents, books, and geospatial datasets such as digital elevation models. Example documents have been presented in Figures 4, 5 and 6. These represent different types of available materials (maps, plans, photographs) that can be used for digital reconstructions, such as: a historical mining map sheet showing the layout of underground workings, a plan of a brickworks, and a photograph of a shaft head. It must be noted that these differ also in quality (e.g. spatial image resolution and spatial reference information).

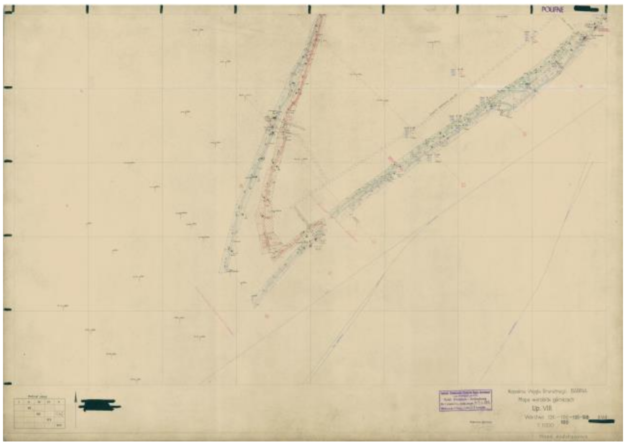

Figure 4. Section of historical mining map collection showing the layout of underground workings in one of the mines (source: Higher Mining Authority archive in Poland)

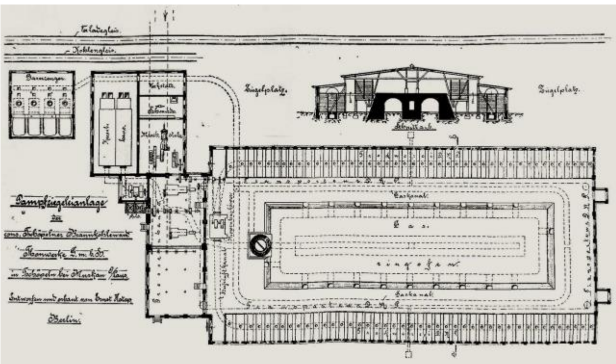

Figure 5. Preserved plan of historical mining map collection showing the layout of underground workings in one of the mines (source: Higher Mining Authority archive in Poland)

Figure 6. Historical photograph of shaft head in underground mining field in Czaple (Poland) (photo circa 1964, source unknown)

The next, and ongoing, phase focuses on field reconnaissance and geodetic measurements of the existing remains of features associated with former mining and industrial activity. Fieldwork activities were conducted to verify and complement the results obtained during the desk research phase. It included site visits aimed at identifying any remaining traces of mining activity, and validating the spatial location of identified mining heritage features. Preliminary laser scanning registrations and the recording of 360° imagery were undertaken to capture the spatial geometry and visual condition of the structures in high detail and to test their applicability. Additional methods, such as photogrammetry and georeferenced surveying (using GNSS receivers) have been employed to ensure accurate spatial referencing and to support the integration of field data with archival sources. This phase aims to produce precise, high-resolution datasets that form the basis for reliable 3D reconstructions and further processing. Figures 7 and 8 show remains of brick-built entrance to underground mine near the village of Czaple (Poland), and remains of cooling tower of a power plant to the north of the village during registration of point cloud data with terrestrial and mobile laser scanning system.

Figure 7. Preserved and secured brick-built entrance to the former underground mine (photo J. Blachowski, 2025)

Figure 8. Field measurements of the power plant remains (photo J. Wajs, 2025)

Both features selected for tests have been surveyed using the Leica BLK360 system. Due to its lightweight and compact design, the set-up was successfully employed in difficult-to-access areas covered with dense and diverse vegetation (Figures 7 and 8). The parameters of the instrument used (measurement range from 0.5 m to 45 m, accuracy ±4 mm @ 10 m, and a maximum acquisition speed of 680,000 points per second with a field of view of 360° horizontally and 270° vertically (Leica Geosystems, 2025) allowed for the acquisition of high-resolution datasets covering the entire surface of both objects of interest in a relatively short time (ca. 45 seconds per station).

The initial stage of office-based processing of the LiDAR data was performed in the Leica Cyclone REGISTER 360 (BLK Edition) software. After importing the complete dataset, its accuracy, completeness, and consistency were verified. The point cloud registration was carried out automatically using VIS information, which integrates image data (the Leica BLK360 records photographs in addition to point clouds at each station) and measurements from inertial sensors (accelerometers and gyroscopes). This enabled the identification of overlapping areas between scans and minimized the need for manual intervention in the alignment process. The final step of the initial processing stage consisted of filtering and decimating the registered dataset (Table 1).

Feature	Mine enterance	Cooling tower
global registration error [m]	0.045	0.032
average scan coverage [%]	72%	82%
raw data (points)	171,660,163	311,483,097
filtered data (million points)	24.11	44.85

Table 1. Data acquisition results using the Leica BLK360 scanner for selected measurement objects

The tested methodology for registering field data for 3D reconstruction will be utilised for the chosen features whose remains are present in the study area.

The final stage of the ongoing research, presented in this paper, concerned 3D modelling of three selected, different test mining heritage features based on the collected point clouds and archival data using manual and AI assisted reconstruction approaches.

The obtained point clouds were used as a geometric reference for further solid-based modelling. We used, the open-source Blender software as it enables efficient modelling and compatibility with AR applications. The 3D object modelling process focused on reconstructing structural elements while maintaining the correct proportions and spatial relationships. Missing fragments were reconstructed manually based on structural analysis and comparison with similar structures based on information retrieved from the collected archival documentations This approach ensured a high degree of geometric accuracy in relation to the actual condition of the objects.

4. Preliminary Results

Desk research enabled the identification of a candidate set of historical underground and open-pit mining features that are hidden or no longer visible in the present-day landscape, the acquisition of input data necessary for 3D modelling and visualization, and the integration of heterogeneous data sources within a geographic information system (GIS) database. The collected materials formed the foundation for subsequent 3D digital reconstructions. Based on the detailed analysis of available materials, particularly their number per object, type, condition, and accuracy, which determine the quality and reliability of the information, as well as the presence of historical context and the completeness of spatial, geometrical, and descriptive data, 10 objects have been selected for 3D digitalisation, with five located on the German side and five on the Polish side of the Geopark. The chosen features include, underground workings with preserved entrance, open-pit, shaft head with conveyor belt system, cooling tower of a power plant, and mining machinery (haulage railway and excavator). Further candidate objects include brick factory, aerial ropeway, and a revitalised industrial building.

An example visualisation of a 3D model of underground corridors, showing the complexity of access galleries, haulage drifts, raises, and shafts used for mining of brown coal digitised from georeferenced historical mining maps and plans is presented in Figure 9. The 3D geometric and attribute information containing location and shape of the features representing multiple underground corridors is stored in GIS geodatabase for further processing and integration with 3D models of mine entrance and shaft head.

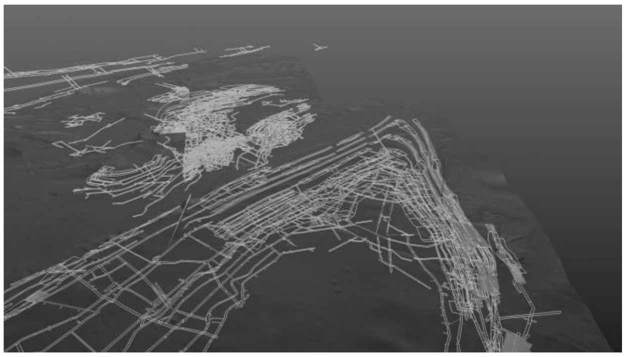

Figure 9. Example 3D visualisation of underground workings digitised from historical documentation.

The second modelled structure was the cooling tower of a power plant located in Czaple (Figures 8 and 10 - top). Recently, only fragments of the structure have survived, including the base of the cooling tower, which served as the primary source of geometric data. The model was developed from a point cloud acquired with mobile laser scanning (described in chapter 3). The upper part of the structure (the shell of the cooling tower) has not survived until present time and was reconstructed using archival descriptions and comparative analysis of similar industrial structures (Figure 10 – bottom)

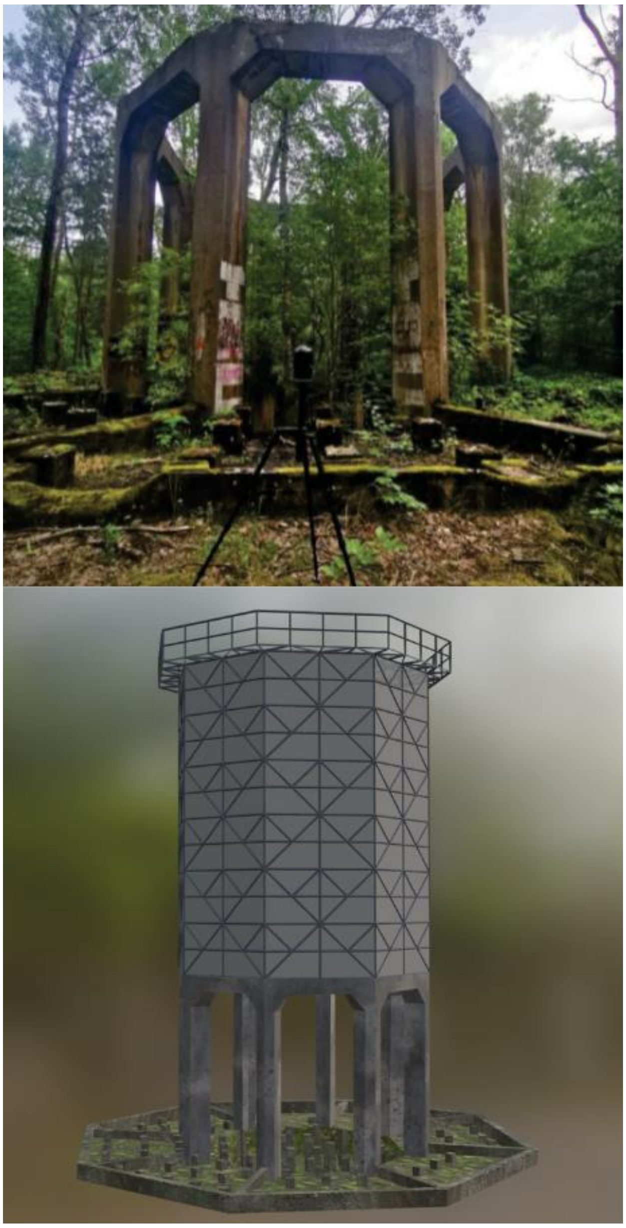

Figure 10. The power plant cooling tower remains (top) and the reconstructed 3D model (bottom).

The third object was the above-ground structure of an inclined conveyor system, which formed part of the brown coal transport infrastructure (Figure 11 - top). The structure no longer survives in situ, and its reconstruction was based solely on a single archival photograph. Therefore, the adopted approach involved in the initial stage test of artificial neural networks algorithms offered by the Meshy AI software (Meshy AI, 2026) and Hiem3D one (Hitem3D, 2026). The Single Image to 3D function was used in both cases to generate the initial model (Figure 11 – middle). The Hitem3D AI tool generated a mesh based on an archival photo presented in Figure 11 – middle. While the AI model accurately captured the overall structure of the object, its dimensions and the angle of inclination, significant geometric irregularities occurred at the connection points in both applications. These include, holes, local surface inflation, and a lack of topological continuity. Structural elements, such as beams and supports, also exhibit irregularities and a lack of linearity. The texture does not accurately represent the actual materials, as it was generated based on a black-and-white photograph. The Hitem3D environment produced more accurate model of the two tested application. It comprises approximately 4 million faces, resulting in a large file size that could hinder its implementation in an AR environment. Therefore, the model was exported to the Blender environment for manual processing and correction of errors of the AI model. These included correction of structural elements geometry and filling in missing parts. The final model contains around 4,000 faces, making it much simpler to integrate into an AR application. The texture was selected from the free BlenderKit set to capture the object’s character as faithfully as possible. The final product will have a texture prepared based on the available historical data. The final model of the conveyor belt is presented in Figure 11 – bottom.

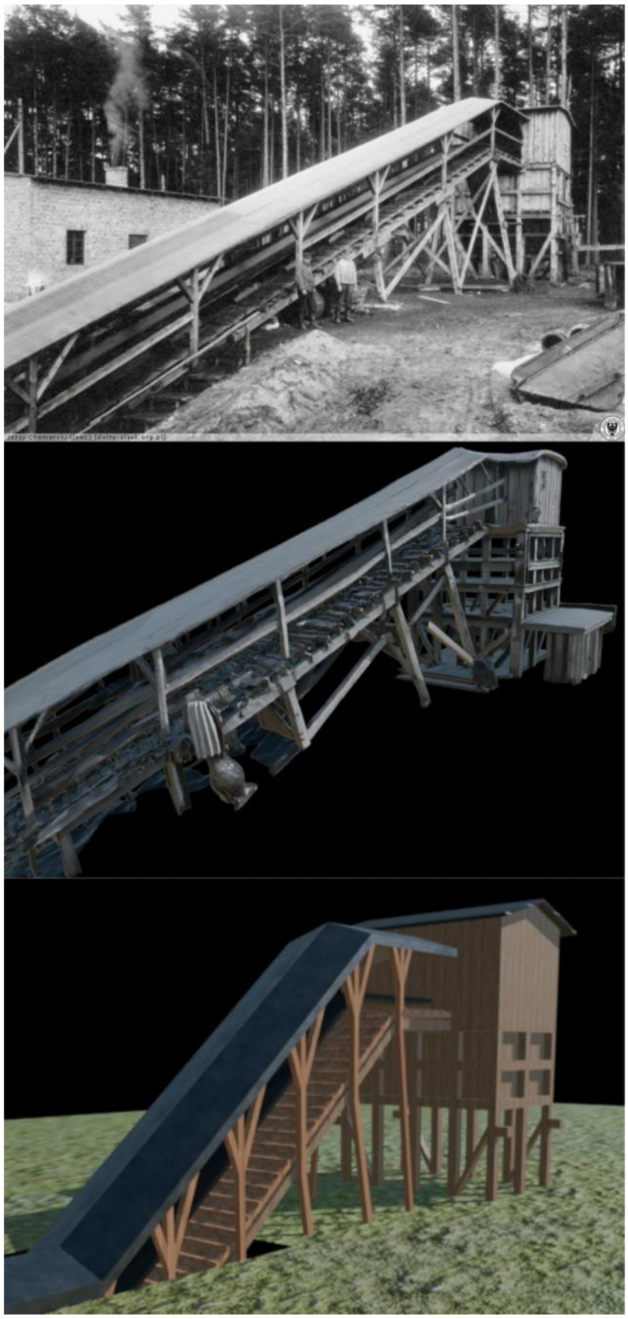

Figure 11. Archive photo of the above-ground structure of the inclined conveyor system (top), AI-reconstructed 3D model (middle), and manually reconstructed model (bottom).

5. Conclusions

This paper presents the methodology adopted for developing 3D models of historical mining heritage features intended for use in an educational and informational geoportal and an AR application dedicated to the history of the Geopark. Three different approaches were applied: digitisation of historical plans, field acquisition of point clouds followed by 3D modelling, and hybrid automatic generation of an initial model from an archival photograph followed by manual refinement.
The methodology relies on two principal categories of spatial data forming the foundation for further processing. The first from historical records, the second from measurements in the field with a point cloud recorded by laser scanning to construct to hybrid 3D models.
The artificial neural network applications offering “automatic” generation of 3D models from single and multi-view images are a promising augmentation of manual reconstruction processes in case of limited number of available documentations as is often the case of historical objects that have not survived to the present day.
The proposed, complete, workflow for developing the final and fully functioning mining heritage geoportal with mobile augmented reality application encompasses among other things:
(1) adaptation of a methodology that enables development of accurate digital reconstructions (3D models) of mining and natural heritage objects, based on the integration of archival materials originating from various analogue sources characterized with varied quality and data representing remains of heritage objects acquired in the field,
(2) design of a dedicated augmented reality and virtual tour environments that provide optimal methods for presenting educational content and information in a clear and engaging way for diverse user groups, including people with disabilities,
(3) preparation of geospatial metadata in accordance with standards for three-dimensional (3D) data, to enable integration with the developed models in augmented reality (AR) and virtual tour environments (Orzechowski et al., 2026),
(4) preparation of user-friendly interactive educational descriptions associated with the reconstructed objects (Li et al., 2023), including prerecorded video descriptions provided by the local guides.
The complete system will be distributed by means of a geoportal with an interactive and narrative maps of the post-mining area presenting detailed spatial and descriptive information on the subsequent phases of mining. It will also provide access to 360° panoramas, interactive 3D visualisations of mining and geological heritage objects, virtual tour through the Geopark and augmented reality application to be used on mobile devices that superimposes 3D models of the reconstructed features directly onto their physical locations.
The aim of the described project is focused not only on documenting and preserving the industrial and mining heritage of the transboundary Polish-German region but also to actively engage diverse audiences by providing interactive experiences. The results should support and encourage local communities, families, pupils, visitors, and tourists to obtain meaningful information and explore the past while promoting awareness of conservation efforts, as well as foster a sense of place and identity.

6. Acknowledgments

The project “Digital journey through Muskau Arch Geopark” is co-financed by the European Union with funds from the European Regional Development Fund as part of the Poland-Saxony 2021-2027 INTERREG Cooperation Program.

The authors would like to express their gratitude to the Municipality of Łęknica (Poland) for their support and collaboration, including providing archival materials.

7. References

Project Digital journey through Muskau Arch Geopark website (2025), https://digitalgeopark.pwr.edu.pl/en/, accessed on 2025-11-15

EGTC, 2025: Geopark Muskau Arch Map, https://www.muskau-arch.eu/our-geopark/map/, accessed 2025-11-15

Hitem3D, 2026: Hitem3D Studio, https://www.hitem3d.ai/learn, accessed 2026-01-19

Koźma, J., Migoń, P., 2024: Mużaków Rampart (Muskau Arch)—The legacy of glacial processes and mining in the UNESCO Global Geopark. In P. Migoń (Ed.), Landscapes and landforms of Poland (pp. 483–497). Springer. https://doi.org/10.1007/978-3-031-45762-3_28

Kuna, J., & Kowalski, Ł., 2020: Exploring a non-existent city via historical GIS system by the example of the Jewish district ‘Podzamcze’ in Lublin (Poland). Journal of Cultural Heritage, 46, 328–334. https://doi.org/10.1016/j.culher.2020.07.010

Kupetz, M., 1997: Geologischer Bau und Genese der Stauchendmoräne Muskauer Faltenbogen. Brandenburgische Geowissenschaftliche Beiträge, 4, 1–19

Leica Geosystems, 2025: BLK360 Spec. Sheet (ver. 2), Heerbrugg: Leica Geosystems AG, https://shop.leica-geosystems.com/sites/default/files/2025-07/BLK360-Spec-Sheet-v2.pdf, accessed 2026-01-09

Li, W., Li, C., Kim, M., Huang, H., & Yu, L.-F., 2023: Location-Aware Adaptation of Augmented Reality Narratives. Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, 1–15. https://doi.org/10.1145/3544548.3580978

Liu, B., Wu, C., Xu, W., Shen, Y., & Tang, F., 2024: Emerging trends in GIS application on cultural heritage conservation: A review. Heritage Science, 12(1), 139. https://doi.org/10.1186/s40494-024-01265-7

Meshy AI, 2026: Meshy.ai Documentation, https://docs.meshy.ai/en, accessed 2026-01-16

Orzechowski, M., Opioła, Ł., Martínez, I. L., Ioannides, M., Panayiotou, P. N., Dutka, Ł., Słota, R. G., & Kitowski, J., 2026: Integrated data, metadata, and paradata management system for 3D Digital Cultural Heritage objects: Workflow automation, federated authentication, and publication. Future Generation Computer Systems, 174, 107964. https://doi.org/10.1016/j.future.2025.107964

Szymanski, R., 2010: Local Heritage, Global Context Cultural Perspectives on Sense of Place, Routledge, London, https://doi.org/10.4324/9781315250304

Urbanski, K., 2007: Łuk Mużakowa jako złożona struktura glacitektoniczna. *Zeszyty Naukowe Inżynieria Środowiska*, 134(14), 179–190. University of Zielona Góra Press