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***BIM in assessing the suitability of historic fortifications
for military purposes, using the example of the gunpowder laboratory
at Boyen Fortress in Giżycko***

Abstract

Building Information Modelling (BIM) is finding increasingly widespread application in the documentation, analysis and conservation of historic buildings, enabling the creation of digital models which can then be used as a basis for a variety of spatial analyses. In the context of fortifications, the ability to use such models to assess their potential suitability in defence scenarios is of particular significance. This article uses the example of the gunpowder laboratory at Boyen Fortress in Giżycko (Poland) to illustrate the application of a simplified BIM model as a tool to support the analysis of the structure's relationship with the surrounding terrain and the conceptual evaluation of various terrain modifications, such as trenches. A digital model of the structure and its surroundings, supplemented by spatial analyses, enabled the assessment of spatial conditions, the identification of potential threat directions, and the comparison of possible solutions for the location and appearance of earthworks. Due to the limitations of the BIM environment in modelling complex terrain geometry at the conceptual stage, generative artificial intelligence tools were used to visualise variants of potential earthworks. The results obtained indicate that even simplified BIM models can provide a useful basis for variant analyses and the documentation of historic structures. At the same time, artificial intelligence-based tools are primarily used in the early stages of conceptual work, supporting the decision-making process by rapidly presenting possible solutions whilst maintaining their illustrative nature.

Key words: BIM, Boyen Fortress, point cloud, trench, artificial intelligence, gunpowder laboratory

Introduction

The authors' focus is on a highly significant example of Prussian fortifications – Boyen Fortress, situated in Giżycko, in the north-eastern part of Poland, in the Warmian-Masurian Voivodeship (Fig. 1a) – and on methods of digital surveying using Building Information Modelling (BIM) technology. The fortress is situated between two large lakes (Niegocin and Kisajno) and is one of the region's most important historic sites (Krahl 2003). The gunpowder labo-

ratory, which is the subject of detailed research, is located in the eastern part of the complex (Fig. 1b). In the 19th-century functional layout of the fortress, this building served as a site for the preparation of explosives and ammunition, and its function differed from that of the military gunpowder store, which at Boyen Fortress was situated in the courtyard of the Światło Bastion. The laboratory is characterised by a distinctive design that can be described as being dug into the ground; that is, from a bird's-eye view, only the corridor leading to the nine rooms is visible. This design served, amongst other things, to protect the fortress's other structures in the event of an explosion (Twierdza Boyen Giżycko n.d.).

Historic sites, such as Boyen Fortress, should be digitised for their own preservation, given their cultural value. BIM enables the creation of digital models of various historic structures that reflect their actual structure and charac-

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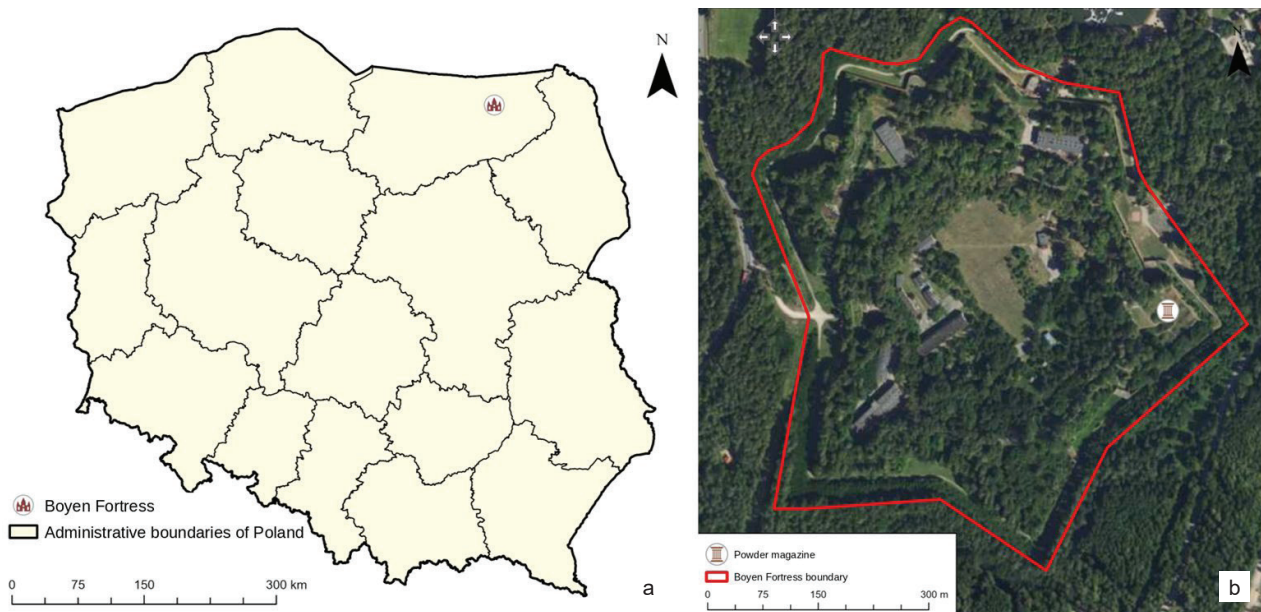


Fig. 1. Location of Boyen Fortress: a) its position in relation to the administrative boundaries of Poland and its provinces (elaborated by M. Żach, K. Zelkowska based on the State Boundary Register of the General Directorate for Geodesy, Cartography and Cadastre [GUGiK]; <https://www.geoportal.gov.pl/>), b) location of the gunpowder laboratory in relation to the boundaries of Boyen Fortress (elaborated by M. Żach, K. Zelkowska based on the GUGiK orthophoto map; <https://www.geoportal.gov.pl/>)

II. 1. Lokalizacja Twierdzy Boyen: a) położenie na tle granic administracyjnych Polski i województw (oprac. M. Żach, K. Zelkowska na podstawie Państwowego Rejestru Granic GUGiK; <https://www.geoportal.gov.pl/>), b) położenie laboratorium prochowego na tle granic Twierdzy Boyen (oprac. M. Żach, K. Zelkowska na podstawie ortofotomapy GUGiK; <https://www.geoportal.gov.pl/>)

teristics. Such models serve not only as documentation of the current state of preservation, but also as a tool facilitating subsequent renovation, revitalisation or reconstruction in the event of damage caused by human activity or natural forces (Borkowski, Olszewska 2024). Creating a model using BIM preserves knowledge of the structure's appearance and condition, which, in the event of damage, would allow for the reconstruction of a historically valuable building, but also enable an assessment of the suitability of the now-listed structure for contemporary military and defence purposes. There are many different ways in which existing historical infrastructure can be utilised for these purposes. One of these is to design a trench as a simulation of potential defensive operations during wartime.

The aim of the authors is to present a methodology for using a simplified BIM model, combining photogrammetric data from unmanned aerial vehicles (UAVs) with a variant analysis of site interventions supported by generative artificial intelligence (AI) tools, in relation to historic fortification structures. The case study focuses on the gunpowder magazine at Boyen Fortress, for which digital documentation of the external condition and an analysis of illustrative conceptual intervention options have been proposed, within the context of the debate on the state's defence readiness, whilst giving absolute priority to the protection of the historic structure.

It is not the authors' intention to advocate the active military use of historic fortifications. Nor does this paper constitute an encouragement to undertake interventions that would alter the substance of the historic monument. The authors maintain that the protection of cultural heritage re-

mains the overriding priority. Any considerations regarding the potential use of historic sites in crisis scenarios are purely of a hypothetical planning nature.

The BIM digital model fulfils a dual role in this study. Firstly, it serves as documentation of the site's state of preservation. This function is purely conservation-related and is independent of any further analyses. Secondly, the model serves as a tool for a preliminary, conceptual spatial assessment of possible on-site interventions. The second function takes on significance in the context of the ongoing debate in Poland regarding the state's defence readiness and in light of the Regulation of the Minister of the Interior and Administration of 2025 on protective and concealed structures (Rozporządzenie... 2025).

It should be emphasised that variant analysis in a digital environment is, by its very nature, intended to minimise the risk of actual, irreversible interventions in a historic monument. It allows for the assessment of alternatives and their consequences even before any on-site actions are undertaken. In this sense, the use of BIM does not conflict with the mission of heritage conservation, but rather supports it. It provides conservationists, defence services and decision-makers with a risk assessment tool.

The innovative contribution of this work does not lie in the UAV data acquisition technology itself, nor in the conversion of point clouds into a Revit model. These procedures are well documented in the relevant literature (Borkowski, Kubrat 2024). The original contribution consists of three elements. The first of these is the integration of variant analysis of conceptual site interventions with the BIM model of the historic fortification. The second element

is the use of generative artificial intelligence tools, such as Gemini 2.5 Flash Image (Nano Banana Pro) and GPT. These tools were utilised to supplement the BIM environment in areas where it exhibits significant limitations. This primarily concerns the modelling of complex terrain geometry in Revit. The third element is a critical analysis of the limitations of this hybrid methodology in conservation applications.

State of research

The field of digital documentation of historic buildings within the BIM environment has been developing for nearly two decades. Heritage Building Information Modelling (HBIM) was introduced by Maurice Murphy and his co-authors (Murphy, McGovern and Pavia 2009) as an extension of the BIM methodology to include historic buildings, whose geometry and construction do not conform to standard component libraries. Subsequent work has focused on developing libraries of parametric elements for historic architecture (Dore, Murphy 2017), the integration of data from terrestrial laser scanning and photogrammetry (López et al. 2018), as well as the challenges associated with the level of detail and reliability of historical models (Penjor et al. 2024).

The number of studies on the application of BIM and HBIM in the documentation of historic buildings is steadily increasing; however, the issue of using simplified BIM models to assess the potential suitability of such buildings in the context of modern defence remains a poorly explored topic. In particular, issues combining spatial analysis based on such a model with conceptual variations in the use of existing terrain and structures are rarely addressed.

Methods

Unmanned aerial vehicles are now a widely used and cost-effective tool for acquiring high-resolution data, as, compared to methods based on, for example, satellite data, they offer the possibility of acquiring data quickly and at relatively low cost (Liu et al. 2022). This study utilised a point cloud of the Boyen Fortress gunpowder laboratory acquired during a flight with a DJI Mini 3 drone. Approximately 300 high-resolution images were captured and subsequently processed photogrammetrically to produce a three-dimensional point cloud depicting the gunpowder laboratory and its immediate surroundings. The resulting average resolution (GSD, Ground Sampling Distance) was 1.71 cm/pixel, which enabled a high-quality representation of the object to be obtained. Following processing of the point cloud in Agisoft software, a point cloud comprising 5,876,161 points was obtained. Due to the absence of an RTK (Real-Time Kinematic) module in the drone used, the point cloud was positioned in the WGS84 coordinate system with a total error of 1.197 m.

The data processing began by importing the photographs into Agisoft and performing the image alignment stage using the Align Photos tool. In this step, the software searched for common points between the photographs, identifying control points, and then calculated the orientation and position of the camera for each shot. On this basis, a preliminary, low-resolution point cloud was gen-

erated, which served as the basis for further processing. In addition, during the scan of the terrain, photopoints were utilised, which also served as an aid during the photo alignment process. In the next step, a dense point cloud was generated for further processing.

The resulting point cloud was imported into Autodesk ReCap, where it underwent initial refinement. At this stage, a transformation to the local reference system (0,0,0) was carried out, as working with geodetic coordinates can cause reading and performance issues within the Autodesk Revit environment. At the same time, the point cloud was manually cleaned by removing noise irrelevant to the analysis, in particular vegetation such as trees. After cleaning, the point cloud was exported to .e57 format and imported into CloudCompare.

In CloudCompare, the orientation of the point cloud was corrected by correctly setting the reference plane. The point cloud was then exported in two formats: LAS and as an ASCII text file. The LAS file was re-imported into Autodesk ReCap and converted to the .rcp format, suitable for use in Autodesk Revit. The point cloud prepared in this way was imported into Revit using the “centre-to-centre” insertion setting. An ASCII text file containing the point coordinates, which were used to create the terrain model, was also imported into Revit. It is important to maintain the correct file structure and to set the separators to commas when importing in CloudCompare, so that the point coordinates are correctly recognised during import.

Based on the imported point cloud, a simplified model of the gunpowder laboratory was created, using the point cloud as a measurement reference for determining the elevations and geometry of the walls and ceiling. The model was then refined to include basic elements such as doors and windows, and materials were assigned to key components. It should be emphasised, however, that the model is for illustrative purposes only and does not fully capture the details, as the photographic data was obtained from a bird’s-eye view, which limits the accuracy of the representation of vertical elements and façade details. The model was visualised using Revit and Lumion. After integrating the modelled building with the site, an integrated BIM model was produced, serving as the basis for further analysis; the next stage involves developing an excavation variant within the modelled structure. During the development of the trench simulation visualisations, two artificial intelligence-based tools were used to generate and manipulate images.

The trench visualisations were created in the ChatGPT environment using the GPT model (OpenAI) and in Gemini 2.5 Flash Image, commonly known as Nano Banana Pro (Google). The individual stages of the methodology employed, covering data acquisition, data processing, the development of the BIM model and the generation of visualisations of the variants, are summarised in a flowchart (Fig. 2).

Trenches as a defensive structure

Trenches are earthworks constituting an anthropogenic feature of the landscape (Franczak, Jucha 2015). They enable relatively safe movement during shelling, as well as the conduct of combat operations. The method of con-

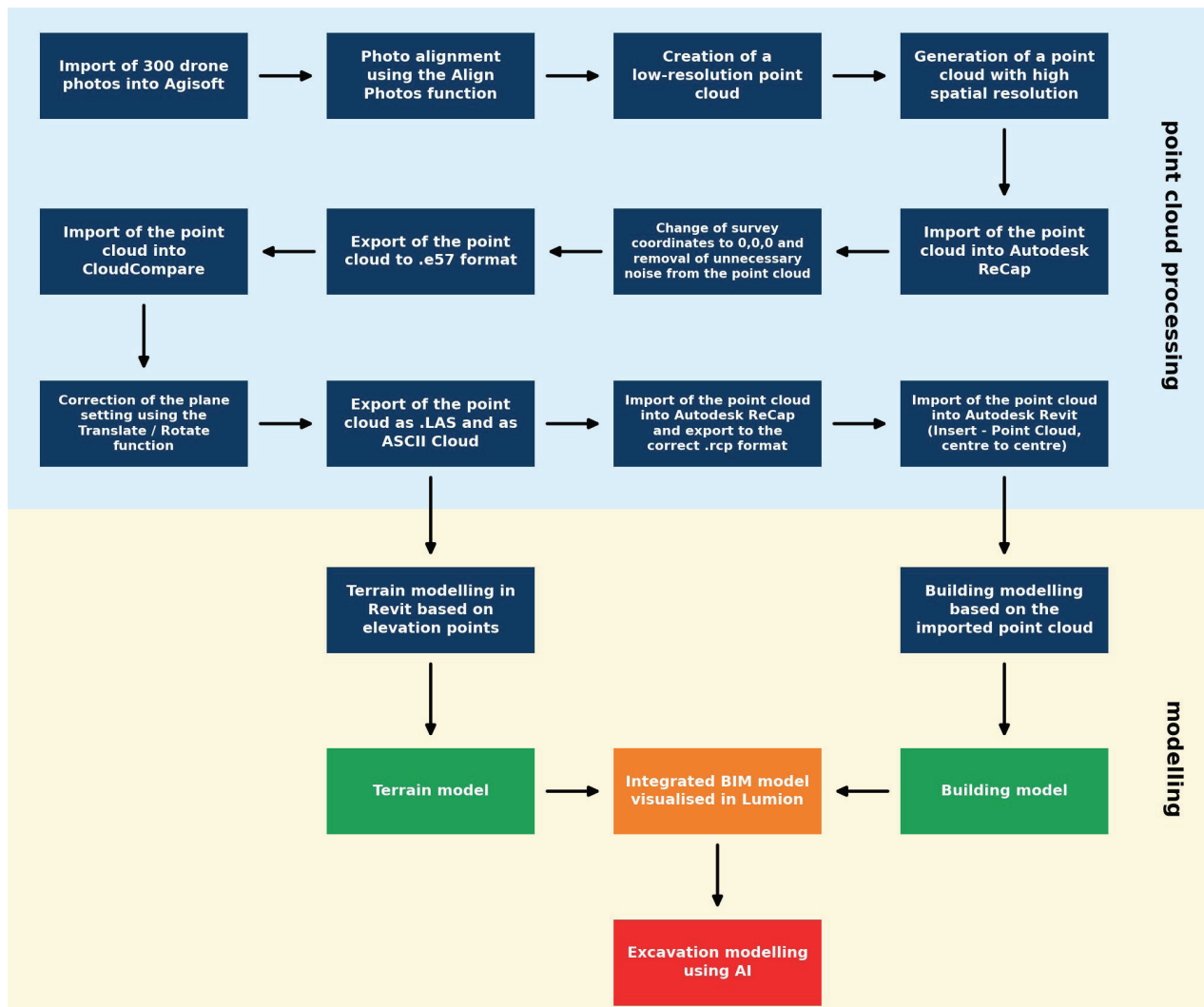


Fig. 2. Diagram of creating a model from a point cloud using photographs obtained by flying a DJI Mini drone (elaborated by M. Żach, K. Zelkowska)

Il. 2. Schemat utworzenia modelu z chmury punktów ze zdjęć pozyskanych w wyniku nalotu dronem DJI Mini (oprac. M. Żach, K. Zelkowska)

structing trenches depends on many different factors, such as the type of subsoil, the topography, the anticipated construction time and the available labour. Trenches are often constructed in the form of a zigzagging trench, which provides protection in the event that the enemy penetrates the interior of the trench (Twierdza Włocławek 2025). At the same time, the method of constructing trenches is regulated by applicable regulations, which specify their basic form, structure and permissible dimensions. In accordance with the Regulation of the Minister of the Interior and Administration, trenches are constructed as narrow excavations with a broken plan, with or without a cover, with temporary shoring made, for example, of wooden formwork or sandbags, or without shoring, whilst maintaining the natural slope angle. The regulations also specify the permissible dimensions of trenches, which, in the case of shored solutions, include a height of 150–220 cm and a width ranging from approximately 80–100 cm at the base to 100–120 cm at the top of the covering, whilst for trenches without formwork or covering, the height is approximately 140 cm and the width is greater at the top, resulting from the use of the natural slope angle (Rozporządzenie... 2025).

In this paper, the trench is treated as an exemplary, hypothetical site intervention, serving as a test case to assess the suitability of a simplified BIM model for the conceptual variation of defensive solutions and for evaluating their spatial and conservation implications.

Results

The simplified model of the gunpowder laboratory (Fig. 3a–d) reflects the external geometry of the building, the topography of the surrounding moat and the relationship between the building's massing and ground level. However, it is important to clearly highlight the methodological limitations of the representation. The photogrammetric data were acquired exclusively from a drone. By its very nature, this precludes direct mapping of the interior of the structure, in particular the corridor leading to the nine laboratory rooms. The underground section of the building remains outside the range of the point cloud obtained from a UAV flight without LiDAR. This is a significant limitation, as it is precisely this part of the building that is key to its historical function. However, this limitation is inher-

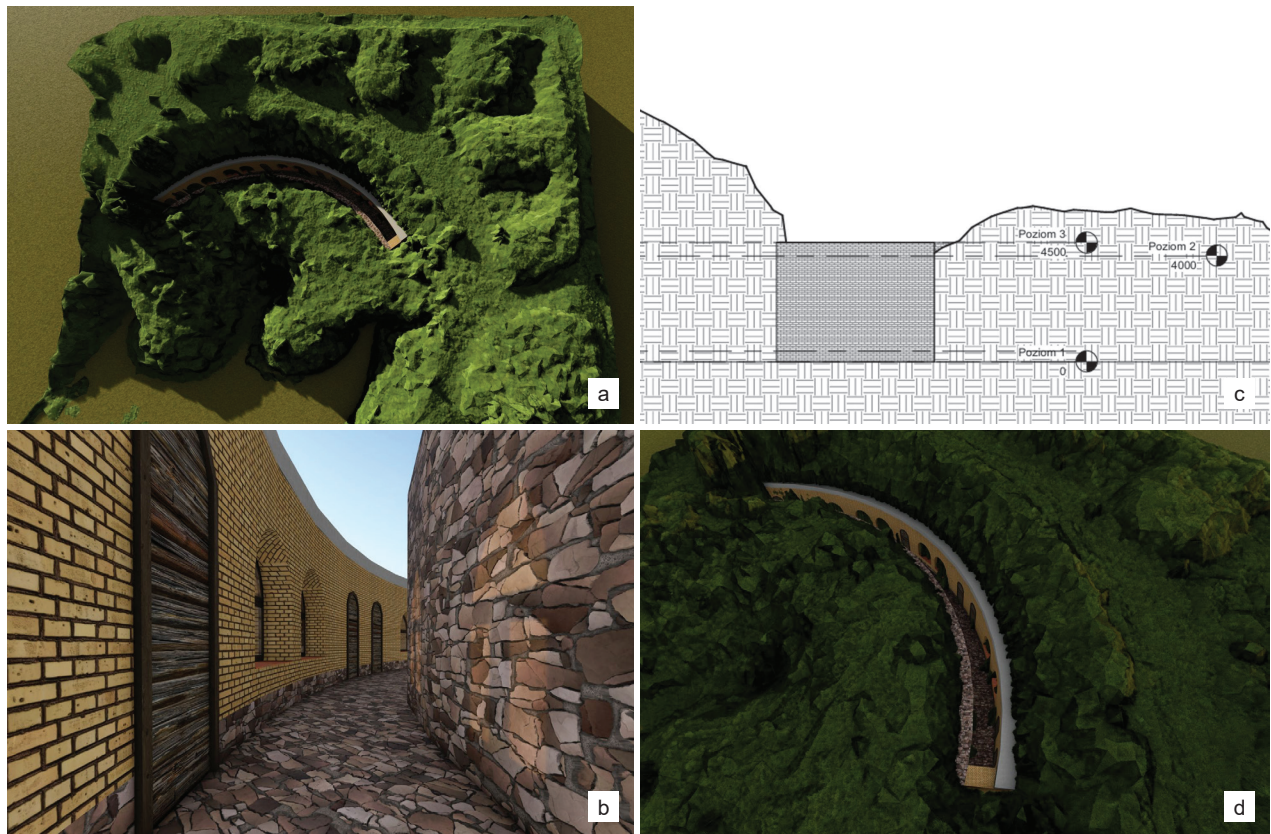


Fig. 3. Model of the gunpowder laboratory at Boyen Fortress: a) topography, b) interior of the building, c) cross-section in Revit, d) model of the Boyen Fortress gunpowder laboratory in Giżycko, including the topography (elaborated by M. Żach, K. Zelkowska)

II. 3. Model laboratorium prochowego Twierdzy Boyen: a) ukształtowanie terenu, b) wewnętrzna część budynku, c) przekrój w programie Revit, d) model laboratorium prochowego Twierdzy Boyen w Giżycku wraz z ukształtowaniem terenu (oprac. M. Żach, K. Zelkowska)

ent to the methodology adopted. A complete representation of the interior would require supplementary ground-based laser scanning (TLS) and interior scanning. The model presented in this paper serves as a building-terrain model rather than a full HBIM model. This is a deliberate choice. The cross-sections shown in Figure 3c therefore illustrate the relationship between the building's structure and the surrounding moat, rather than its internal functional layout. A key outcome of the work carried out is the ability to use the developed BIM model as digital documentation of the building's external condition. It records the geometry of the gunpowder laboratory and its relationship with the surrounding terrain at the time the data was collected; thus, in the event of partial or total destruction caused by military action, natural disasters or deterioration over time, the model can facilitate renovation or reconstruction work.

As part of the assessment of the military potential of the Boyen Fortress gunpowder laboratory, simulations were carried out to explore the possibility of transforming the site by creating a visualisation of a trench. A variant analysis was conducted on the immediate surroundings of the facility, taking into account the terrain, existing greenery, spatial conditions and possible attack scenarios.

A threat scenario has been adopted in which the direction of a potential attack is from the north-east (Fig. 4). From the selected alternative location of the trench, the Boyen Fortress area directly adjoins the built-up area of Giżycko,



Fig. 4. Visualisation of the attack scenario against the background of an orthophotomap (elaborated by M. Żach, K. Zelkowska based on an orthophotomap; <https://www.geoportal.gov.pl/>)

II. 4. Wizualizacja scenariusza ataku na tle ortofotomapy (oprac. M. Żach, K. Zelkowska na podstawie ortofotomapy; <https://www.geoportal.gov.pl/>)

making this direction one of the most accessible in terms of transport links and potentially the most vulnerable to an advance by enemy forces. The scenario assumed that, following the capture of the town, the Boyen Fortress area could serve as one of the last points of resistance. Furthermore, a key factor influencing the choice of the trench's location is the natural terrain barriers surrounding the fortress. To the east and north-west, the fortress area lies in close proximity to large lakes (Niegocin and Kisajno). These significantly restrict direct access to the fort and hinder the conduct of land manoeuvres. From the south-west, a potential advance towards the fortress is possible, though it is also hampered by the presence of smaller lakes, such as Tajty, Duże Wilkasy and Małe Wilkasy, which constitute additional natural obstacles. At the same time, from a broader regional perspective, the northern and north-eastern directions are areas from which, geographically speaking, forces posing a potential threat from beyond Poland's borders could move into Polish territory; in a hypothetical threat scenario, this justifies the potential location of the trench. Furthermore, it should be noted that, from the southern side, despite the presence of terrain obstacles, communication is possible; and in the assumed siege scenario, the transport routes located there could serve as a logistical base and facilitate supplies to the fortress area.

The appearance of trenches – that is, their form, shape and length – depends on many factors, the key ones being the terrain conditions, the time available for construction and their intended function. Trenches can fulfil several basic functions, including combat, defence and communication. However, two types of trenches can be distinguished: firing trenches, which mark the front lines, and communication trenches, which connect them (Doyle 2019). As part of the variant analysis carried out, two potential locations for a trench were identified in the immediate vicinity of the gunpowder laboratory building. Using artificial intelligence and based on the attached .jpg image of the gunpowder laboratory model (Fig. 3a), two variants of the trench's location and appearance were generated. The process of generating the visualisations was based on descriptive text prompts, which took into account the trench's alignment, its relationship with the terrain, the proximity to the gunpowder laboratory building, and general characteristics of earthworks, such as a zigzag shape or the shielding of positions. The generated visualisations are for illustrative purposes only. They serve to illustrate the spatial differences between the variants. The geometric parameters of the trenches adopted at the stage of generating prompts for the AI tools were consistent with the dimensions specified in the Regulation of the Minister of the Interior and Administration of 2025. This applies to heights of 150–220 cm and widths of 80–120 cm for the shored variants (Rozporządzenie... 2025). It should be noted, however, that the accuracy of dimension representation in images generated by diffusion models remains limited. These tools capture proportions and spatial character, but should not be treated as technical documentation meeting formal requirements. Full detailed design drawings for the fortifications would need to be developed in a separate, dedicated design process, in accordance with military regulations and guidelines.

The first variant (Fig. 5a) involves the construction of a long trench with a zigzagging and highly winding course, situated in the upper part of the site, in the immediate vicinity of the gunpowder laboratory, on the eastern side. The trench's course makes use of the natural topography. Its length allows for the creation of a continuous line of defence and the establishment of a front line, as well as the deployment of several firing positions. The trench can also serve a communication function, as it allows the garrison to move relatively safely within the trench. It is also partially extended closer to the gunpowder laboratory building, thus providing better access to its rooms. The sharply zigzagging shape of the trench limits the possibility of flanking fire and reduces the effects of a shock wave (Doyle 2019). This variant requires a greater amount of earthworks.

The second variant (Fig. 5b) involves constructing a trench that is also zigzag-shaped, but with a less winding course. It is also situated in the upper part of the site, but is shorter in length. The limited length of the fortification means it serves a more combat-oriented function and can act as an observation and cover position. The smaller number of bends and the shorter length facilitate quicker construction and reduce the scope of earthworks. This makes this variant a more viable option where construction time is limited. At the same time, its defensive potential is more limited compared with the first variant.

A comparison of the options highlights, above all, the differing nature of the proposed solutions and the associated design trade-offs. The first option offers greater potential in terms of territorial defence and transport functionality, which is its main advantage in the context of protracted hostilities. At the same time, this solution involves a much greater need for terrain modification and more demanding construction requirements. Option two is characterised by a shorter construction time, which may be its key advantage in situations requiring the immediate securing of the area. However, the reduced length and simpler layout of the fortification result in a lower level of protection and reduced functionality. This comparison shows that the proposed variants do not compete directly with one another, but can be utilised in various situations where the priorities may be either to maximise defensive potential or to minimise implementation time and interference with the terrain. This approach confirms the validity of applying variant analysis as early as the conceptual stage.

The choice of the immediate vicinity of the gunpowder laboratory as the area for variant analysis was dictated by three methodological considerations. Firstly, a coherent, high-resolution point cloud was available for this area. This enabled reliable modelling of the terrain.

Secondly, the aim of the study was not to identify the tactically optimal location for fortifications. Such an aim would have required an analysis of an area extending well beyond Boyen Fortress. It would also have required consideration of military doctrine and current defence service guidelines. Instead, the aim was to demonstrate a methodology for exploring variants of site interventions within a BIM environment, using a specific, well-documented case study.

Thirdly, the analysis in the immediate vicinity of the historic monument highlights a significant conservation constraint. None of the proposed variants is recommended for



Fig. 5. A simulation of a trench created using: a) Nano Banana Pro – variant 1 (source: Nano Banana Pro – Gemini 2.5 Flash Image; Google), b) ChatGPT – variant 2 (source: ChatGPT; OpenAI)

Il. 5. Symulacja okopu utworzona za pomocą: a) Nano Banana Pro – wariant 1 (źródło: Nano Banana Pro – Gemini 2.5 Flash Image; Google), b) ChatGPT – wariant 2 (źródło: ChatGPT; OpenAI)

Table 1. Evaluation criteria and comparison of conceptual variants of trenches generated using AI tools (elaborated by K. Żelkowska, M. Żach)
Tabela 1. Kryteria oceny i porównanie koncepcyjnych wariantów okopów wygenerowanych z wykorzystaniem narzędzi AI
(oprac. K. Żelkowska, M. Żach)

	Variant 1 (Fig. 5a)	Variant 2 (Fig. 5b)
Location	northern and eastern parts of the site	northern part of the site
Length	long	short
Course	very winding, zigzagging	zigzagging
Primary function	defensive and communication	observation and combat
Defensive potential	high	medium
Extent of earthworks	greater	smaller
Design assumptions	a description incorporating a long, zigzagging trench adapted to the natural terrain, providing cover for positions and enabling communication along the line of defence	a description involving a short, zigzagging trench with a simplified layout, designed for rapid construction and to serve as an observation and cover post
Compliance with Ministry of the Interior and Administration Regulation 2025	prompt specifications in accordance with the dimensions (height 150–220 cm, width 80–120 cm); illustrative representation	the design of the prompt complies with the dimensions (height 150–220 cm, width 80–120 cm); illustrative representation

implementation given the current condition of the site. This is due to the risk of damage to the preserved earthworks, such as cross-walls and parapets, as well as the underground section of the laboratory. The analysis of alternative options is therefore illustrative in nature. It demonstrates how a BIM-based analysis of alternative options enables the identification of conflicts with the historic fabric even before a decision is made on site.

Discussion

The proposed options for the location of the trenches in the immediate vicinity of the gunpowder laboratory are

in clear conflict with the preserved historic earthworks of Boyen's Fortress. This applies to the cross-walls, parapets and the structure of the moat. Carrying out such works in the current condition of the site would lead to irreversible damage to the historic fabric. Deeper earthworks could also endanger the underground, masonry section of the laboratory. From a conservation perspective, none of the options presented can be recommended for implementation. This would require a prior comprehensive Heritage Impact Assessment (HIA). The consent of the relevant heritage conservation officer would also be required.

It is precisely this observation that constitutes one of the main conclusions of this study. Variant analysis within a BIM

environment allows for the early identification of conflicts with the historic fabric. The digital model reveals spatial conflicts which, at the preliminary concept stage, would not be obvious without visualisation. In this way, BIM becomes a tool for protecting heritage from hasty planning decisions. It is not, however, a tool that facilitates intervention.

From the perspective of conservation practice, it would be most appropriate to locate any contemporary fortifications outside the boundaries of the historic complex. Variation analysis in BIM enables a rapid comparison of such alternatives outside the fortress with options within it. This provides conservation arguments in favour of the former solution.

The use of the full BIM suite and AI tools to design a single, limited section of earthworks could, in isolation, be disproportionate to the scale of the problem. In this paper, however, the scope of the analysis was determined by its demonstrative function. The selected site and the limited length of the variants allowed for a clear presentation of the methodology within a single academic article.

The true value of the proposed approach only becomes apparent when applied on a larger scale. This applies to analyses covering entire fortification complexes, networks of critical infrastructure, or cultural heritage portfolios. In such cases, a unified methodology enables a systematic comparison of variants across multiple sites. In this sense, the gunpowder laboratory at Boyen Fortress serves as a proof-of-concept in this work, rather than the main focus of the project investment.

BIM models of fortifications, whether simplified or more detailed, can serve as a valuable tool to support spatial analyses, the evaluation of alternatives and the assessment of potential scenarios. It is particularly advantageous to prepare such models and analyses at a time when there is no immediate threat and when it is possible to collect and analyse data without time pressure. It is worth emphasising that creating a simplified BIM model, based on a point cloud, does not require highly advanced HBIM expertise. Nowadays, spatial data does not have to be acquired exclusively using expensive platforms, and the equipment used for data collection can often be significantly cheaper (commercial drones or even a mobile phone and a suitable app). This lowers the technological barrier to entry and enables organisations with limited technical resources to carry out such work. It should be noted, however, that the equipment used affects the accuracy and reliability of subsequent analyses, which should be taken into account when interpreting the results. Carrying out scans and creating models during periods when there is no threat brings many benefits. The finished model can be immediately used to carry out conceptual analyses, explore alternatives, and develop action plans which, in the event of a conflict, could be implemented much more quickly and efficiently. From a national security perspective, an unquestionable advantage of using a BIM model is precisely the ability to carry out scenario analyses, compare options for field interventions, assess their spatial consequences, identify potential problems even before field operations commence, and conduct preliminary risk predictions. BIM can thus serve as a tool to support decision-making processes in crisis situations. Furthermore,

in the event of a building's destruction as a result of military action or other causes, a model created beforehand can serve as digital documentation to support the reconstruction or repair process. HBIM demonstrates just how important it is to have models of historic buildings. Traditional methods of documenting historic buildings, such as technical drawings, textual descriptions or photographs, are often incomplete, scattered and insufficient for conducting comprehensive spatial analyses and making conservation decisions (Penjor et al. 2024). Furthermore, it is worth noting that, in the case of reconstruction, it is much easier to use a model previously created using a point cloud whilst the building still stands, rather than using individual photographs, from which a model is only created after a great deal of work. It should be noted, however, that the model developed for the Boyen Fortress gunpowder laboratory is simplified in nature and does not constitute a full HBIM model. The data was obtained mainly from aerial views, which limits the accuracy of the representation of the building's architectural and structural details. To develop a model with a higher level of detail, it would be necessary to carry out a scan from ground level and a detailed survey of the site. At the same time, the level of detail adopted proved sufficient to achieve the aim of the study, which was to explore different options and visualise the potential location of the trenches.

Significant tool-related limitations were identified during the implementation of the project activities. Autodesk Revit, as a parametric environment, is not fully suited to modelling and editing terrain with complex topography and a large number of points. Attempts to adjust the terrain levelling proved particularly problematic, placing a significant computational load on the programme and, consequently, leading to instability and crashes. In practice, this made it difficult to make any corrections to the terrain model. A solution in such a situation would be to use other tools dedicated to working with terrain models, and to import simplified geometry into the BIM environment in order to improve the quality of the work. However, in the work carried out in this article, this approach was not adopted, which limited the ability to model and modify visualisations of trench variants. Consequently, a key element was the use of artificial intelligence-based tools to visualise trench variants. The use of AI enabled the rapid presentation of spatial concepts without the need to manually model all variants, which significantly reduced the time required for the work. These visualisations can be regarded as a stage preceding the actual design process, allowing the selection of the most rational solution for further, manual development within a BIM environment. It should be emphasised, however, that AI-generated visualisations are for illustrative purposes only and do not constitute a professional simulation. Solutions based on generative artificial intelligence are therefore used in the early stages of the design process, primarily at the conceptual stage, where they enable the rapid generation of new ideas, thereby significantly increasing the efficiency of design work (Li et al. 2025). Nevertheless, the rapid development of artificial intelligence suggests that, in the future, these tools may offer an increasingly high level of accuracy and become a significant aid in the design process.

Conclusions

The topic addressed in this article – the use of BIM to assess and prepare historic fortifications formerly used for military purposes with a view to conducting variant analyses of defence simulations – is rarely discussed in contemporary specialist literature or public debate, despite the fact that it combines two important issues: heritage conservation and national security. Given the current geopolitical situation, greater attention should be paid to the issues of national security and preparedness, including the preparation of historic sites for potential defence in the event of an armed conflict. It is worth considering the creation of digital models of sites during peacetime as a preventative measure, which can be used in a crisis situation for rapid scenario analysis and the evaluation of alternative concepts without the need to commence survey work on a given site under pressure and logistical constraints. In this context,

BIM serves as a useful tool for supporting variant planning and spatial risk assessment, as it enables us to organise key information regarding the geometry of a structure and its surroundings. It would therefore be worth considering the creation, in peacetime, of a database of BIM models of critical infrastructure and historic buildings, which would be regularly updated as part of heritage protection and crisis management. Such a database would enhance the state's preparedness in the event of a conflict and would also support conservation objectives. It should be noted that the creation of such a database should be preceded by the definition of clear criteria and standards, so that the models it contains are as standardised as possible and ready for immediate use without the need for corrections, which would facilitate and accelerate work on the collected models.

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Streszczenie

BIM w ocenie przydatności zabytkowych fortyfikacji do celów militarnych na przykładzie laboratorium prochowego Twierdzy Boyen w Giżycku

Building Information Modeling (BIM) znajduje coraz szersze zastosowanie w dokumentowaniu, analizie oraz ochronie obiektów zabytkowych, umożliwiając tworzenie cyfrowych modeli, które następnie mogą być wykorzystywane jako podstawa do różnorodnych analiz przestrzennych. W kontekście obiektów fortyfikacyjnych szczególne znaczenie ma możliwość wykorzystania takich modeli do oceny ich potencjalnej przydatności w scenariuszach obronnych. W artykule na przykładzie laboratorium prochowego Twierdzy Boyen w Giżycku (Polska) przedstawiono zastosowanie uproszczonego modelu BIM jako narzędzia wspierającego analizę powiązań obiektu z otaczającym terenem oraz koncepcyjne wariantowanie ingerencji terenowych,

takich jak okopy. Cyfrowy model obiektu i jego otoczenia, uzupełniony o analizy przestrzenne, umożliwił ocenę uwarunkowań przestrzennych, identyfikację potencjalnych kierunków zagrożeń oraz porównanie możliwych rozwiązań lokalizacji i wyglądu umocnień ziemnych. Ze względu na ograniczenia środowiska BIM w zakresie modelowania złożonej geometrii terenu na etapie koncepcyjnym wykorzystano narzędzia generatywnej sztucznej inteligencji do wizualizacji wariantów potencjalnych umocnień ziemnych. Uzyskane rezultaty wskazują, że nawet uproszczone modele BIM mogą stanowić użyteczną podstawę do analiz wariantowych oraz dokumentacji obiektów zabytkowych. Jednocześnie narzędzia oparte na sztucznej inteligencji znajdują zastosowanie przede wszystkim na wczesnych etapach prac koncepcyjnych, wspierając proces podejmowania decyzji poprzez szybkie przedstawienie możliwych rozwiązań, przy zachowaniu ich poglądowego charakteru.

Słowa kluczowe: BIM, Twierdza Boyen, chmura punktów, okop, sztuczna inteligencja, laboratorium prochowe