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Integration of BIM and GIS in Predicting Flood Damage to Historic Buildings: The Case of Auschwitz Death Camp I

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Abstract

Climate change is contributing to an increase in the frequency and intensity of flooding, especially in urban areas, where disruptions to the hydrological cycle increase the risk of "urban flooding." Buildings of historic value are particularly vulnerable, with damage associated with irreversible loss of cultural heritage elements. This study focuses on the use of BIM (Building Information Modeling) and GIS (Geographic Information System) in flood loss analysis of historic buildings. The article discusses a case study of Building No. 17 located on the site of the former Auschwitz I extermination camp. Two flood scenarios were simulated for the study. The results of such analyses can be an important tool in determining the need for additional measures to protect historic buildings from the effects of extreme weather events. The study underscores the need to develop methods for predicting damage to monuments in the face of extreme natural phenomena, especially floods, which pose an increasing threat.

Key words: BIM technology; GIS technology; damage costs; flood risk; death camp.

1. Introduction

In the face of accelerating climate change, humanity is facing more frequent and intense extreme events, such as floods (Bartkiewicz et al., 2005). In Europe, the most common cause of floods is intense and/or prolonged rain. They are a global problem that humans are still not dealing with effectively, and the material losses associated with them have been increasing for decades (Kundzewicz, 2012). Urban areas are particularly at risk; urban areas are experiencing a disruption of the hydrological cycle, resulting from an increase in impervious surfaces, a significant reduction in rainwater retention and infiltration capacity. This results in "urban floods" during heavy rains, which pose a lethal threat to people and cause huge material losses (Mańkowska-Wróbel, 2014). Equally dangerous are river floods, which have been identified as one of the main dangers in the Central European region. From the 1990s to 2024, Poland was hit by four floods that had the character of natural disasters. These events occurred in 1997, 2001, 2010 and in 2024. One of the many regions of Poland that suffered the most during these phenomena was Lower Silesia and its capital, historic Wroclaw (Kuźmiński, 2016). Many historically valuable monuments are located near rivers in areas prone to flooding. In the event of flooding, such buildings can be destroyed and their historical value irreversibly lost. Heritage plays an important role in Poland's social and economic development, creating a significant part of GDP in the service and manufacturing sectors and providing stable jobs (Helpa-Liszkowska, 2013). That is why it is so important to protect monuments, which are one of the elements of Poland's cultural heritage. To protect cities from flooding, dykes are built, but in the case of very intense rainfall, dykes are not sufficient protection, there are breaks or water overflows the top of the dyke (Slizewski, 2007). That is why it is so important to protect monuments,

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2. Use of BIM technology in predicting building damage

BIM is the basis for realizing the idea of a digital twin of an existing or planned building object. The idea of BIM assumes that the model accompanies the facility throughout its life cycle and, as far as possible, should faithfully represent the actual state of the facility. Any planned change (modernization, reconstruction) in the facility should first be simulated in the BIM model. The BIM model can be helpful in managing renovations (estimating costs, scheduling or monitoring construction work), as well as in the ongoing maintenance of the BIM is finding increasing use in facility management (FM) during operation. A major advantage of BIM technology is the ability to perform simulations (Borkowski, and Maroń, 2023). Using various plug-ins, it is possible to combine BIM software with other technologies, which gives the possibility to simulate the behavior of building structures in various situations, such as during extreme natural phenomena. BIM-based structural analysis makes it possible to estimate the cost of building damage in the event of natural hazards, such as earthquakes (Mousavi et al., 2022). There are numerous studies in literature using BIM technology in simulating the behavior of buildings during seismic loading, estimating the cost of earthquake damage and the environmental impact of the resulting damage (Mousavi et al., 2022; Alirezaei et al., 2016; Xu et al., 2019). The literature review identified a research gap in the scarcity of studies on estimating flood damage to buildings.

3. HBIM

Cultural heritage is threatened by natural disasters. Fires, earthquakes, floods, tsunamis, land and mudslides, winds and tropical storms are among the main causes of loss and damage. These disasters result in the loss of irreplaceable artistic and cultural assets and are costly. Damage to cultural heritage is further increased in the absence of proper risk assessment, evaluation and minimization measures (Taboroff, 2003). Forecasting damage to buildings therefore seems particularly important for buildings with high historical value. To effectively manage a historic building, it should have its own HBIM (Heritage Building Information Modeling) model. However, the use of BIM technology in the heritage field requires a constant trade-off between geometric accuracy, semantic richness (non-graphic data) and parametric behavior of the model. The literature is dominated by cases of creating HBIM models based on LIDAR (Light Detection and Ranging) laser scanning, e.g. (Borkowski, and Maroń, 2023). In the present study, however, the decision was made to develop an HBIM model of the building based on archival plans and drawings depicting the building selected for analysis.

4. Research subject

One of the buildings located at the Auschwitz I Memorial and Museum was selected for the study. The beginning of the brick barracks complex dates to 1917. The facility was commissioned by the Austro-Hungarian government to create a colony for emigrants and seasonal workers but operated for less than two years. After the end of World War I, the area came under the ownership of the just-revived Poland, and the largest part of the reclaimed land was allocated for a military camp subordinate to the Polish Army. The barracks survived until the outbreak of World War II, and in 1940 Erich von dem Bach-Zelewski proposed that a planned concentration camp be located there („Oboz koncentracyjny w Oświęcimiu – zbudowano w 1917 roku", 2012).
The analyzed complex is in southern Poland, in Lesser Poland Province, within the Oświęcim County, within the administrative boundaries of the city of Oświęcim. The nearest major urban center is Krakow, one of the most important and most visited tourist cities in Poland (Fig. 1).

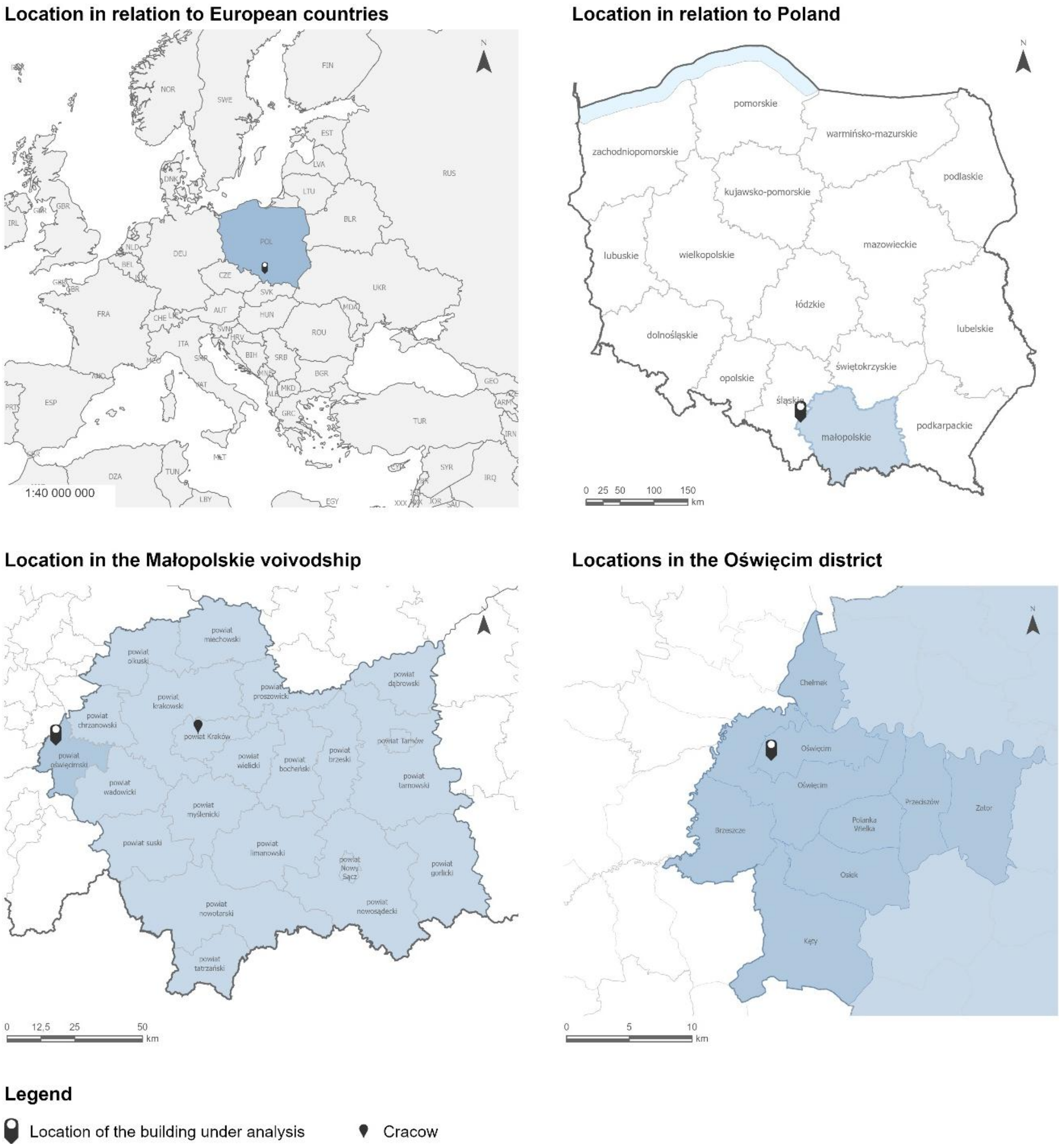

Fig. 1. Location of the analyzed facility against the background of Europe, Poland, Lesser Poland Voivodeship and Oświęcim County (own elaboration)

The subject of the study was Building No. 17, located on the site of the former Auschwitz I concentration camp (Fig. 2). This building, which originally served as a residential barrack, is in the central axis of the camp, directly adjacent to the main square. The selection of the building was based on the availability of source materials that were able to be collected in preparation for the research work.

In 2021, work was completed to significantly improve flood protection in the Oświęcim municipality („Lepsza ochrona przeciwpowodziowa Oświęcimia i okolic", 2021). The key premise of the work carried out was not only to increase the safety of area residents, but also to ensure effective protection of the cultural and historical heritage that is the Auschwitz - Birkenau Museum.

According to maps prepared by the State Water Company, building number 17 is in an area of special risk of flooding in the event of failure, damage or destruction of a water damming structure (PGW Wody Polskie n.d.). The projected consequences of such an event include the possibility of flooding with depths ranging from 0.5 meters to 2 meters, which could pose a significant threat to the infrastructure and cultural assets located in the area (Fig. 3).

Fig. 2. Location of the investigated object against the background of the former Auschwitz I concentration camp area (own elaboration)

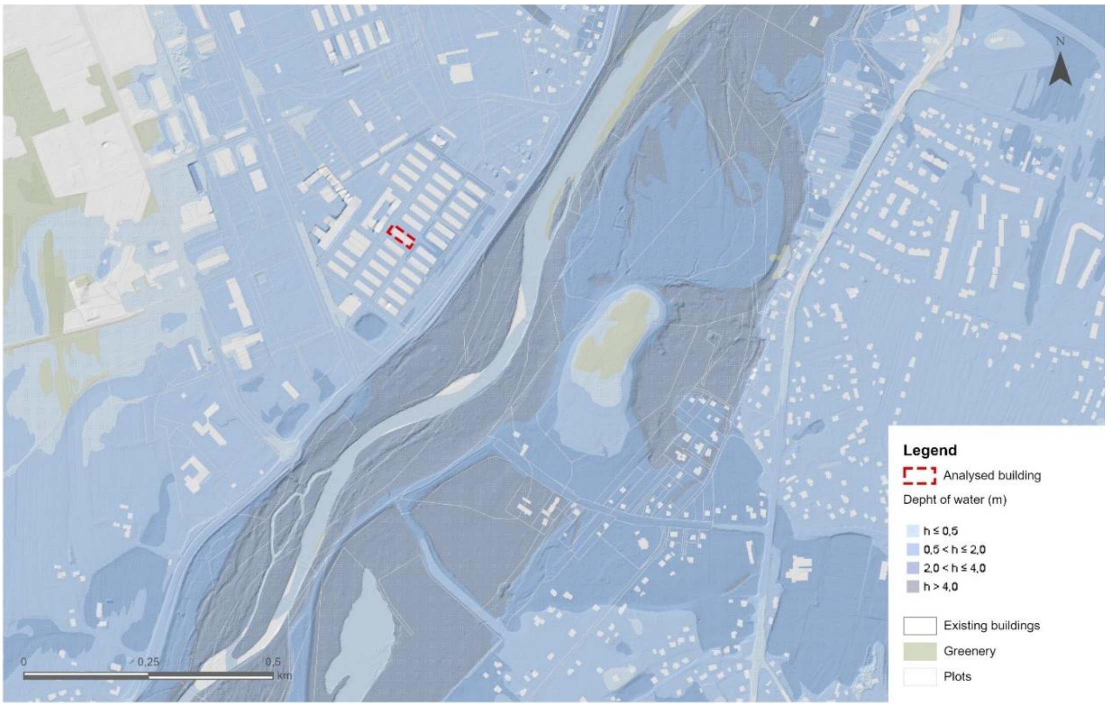

Fig. 3. Projected water height in case of failure, damage or destruction of damming structure (own study)

5. Materials and methods

Various data sources were used to develop the BIM model (Table 1; Table 2). The basis in the modeling process were plans and design drawings supplemented by photographic documentation. Autodesk Revit software was used to create the HBIM model of the building. The integration of BIM and GIS technologies was then performed - the created building model was imported into ArcGIS Pro software.

Table 1 . Data sources for the development of the HBIM model

Lp.	Data sources for the development of the HBIM model
1	Archival projections obtained from the website of the National Fund of the Republic of Austria for Victims of National Socialism
2	Geoportal service
3	Google Earth service
4	BIMobject.com service

Table 2. Data sources for the development of the GIS model

Lp.	Data sources for the development of the GIS model
1	Geoportal service
2	Hydroportal service
3	SIP service for the Oświęcim district

The development of the BIM model of the analyzed building (Fig. 4) began locating it in the appropriate position in the 1992 Geodetic Coordinate System (PUWG 1992). For this purpose, using publicly available data from the Geoportal website and QGIS software, the boundaries of the analyzed building were exported in .dxf (Drawing Exchange Format). The existing walls of the building were then mapped using Autodesk AutoCAD software and acquired historical materials, and Autodesk Revit software was used to further develop the BIM model. Due to limited access to detailed building data, the model created includes only basic structural elements, such as walls, windows, doors, stairs and the roof. To ensure the visual consistency of the model, Revit-specific system element families were used. These families were obtained from publicly available sources in the public domain. Thanks to the archival sources, it was possible to map the wall layout of the first floor, which is most vulnerable to flood damage. The next step in the process was to assign appropriate geodetic coordinates to the object to enable further operations in a GIS technology environment. For this purpose, X and Y coordinates were selected from the 1992 National Geodetic Coordinate System (PUWG 1992), which were obtained from the Geoportal service. These coordinates were assigned in a point-based manner, which allowed the model to be precisely located in space. To ensure the model's compatibility with GIS software and enable its visualization in a spatial environment, the model was exported to IFC (Industry Foundation Classes) format. This format is widely used in the exchange of data between various BIM and GIS tools (Gotlib, and Wyszomirski, 2018), which facilitates the integration of the model into further stages of spatial analysis.

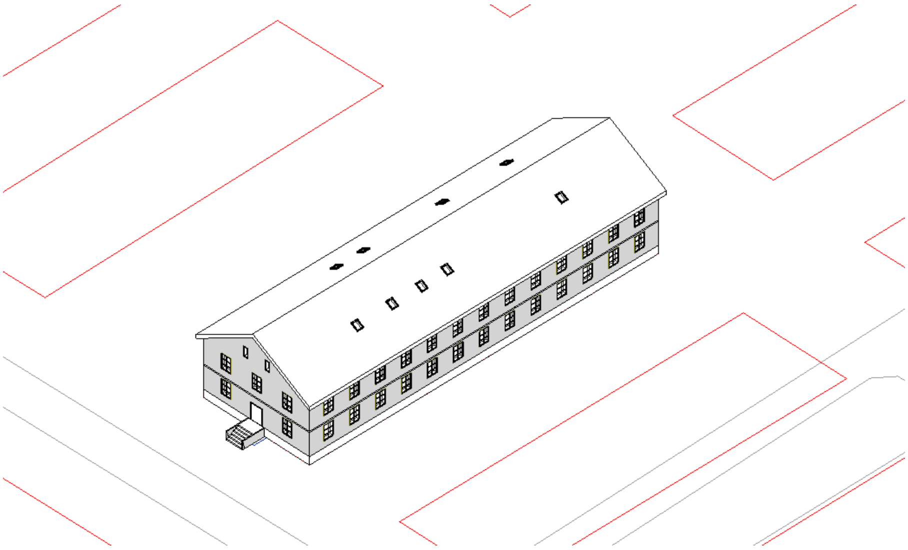

Fig. 4. Model of building No. 17 in Autodesk Revit software (own study)

6. Integration of BIM and GIS technologies

To integrate the GIS environment with the BIM model, a local scene was created in ArcGIS Pro. Using publicly available data, DMT (Digital Terrain Model) of the analyzed area and existing buildings in LoD2 (Level of Detail 2) in the CityGML standard were obtained from the Geoportal service. Using the obtained data, a local scene with existing buildings located at the appropriate height above sea level was developed. The created BIM models in IFC format were imported into the created scene (Fig. 5). Using the publicly available WMS (Web Map Services) standard, a layer depicting the flood hazard area of the Tresna Reservoir as a result of the destruction or damage of the damming structure was loaded into the analyzed scene. The conversion resulted in a flood hazard layer in .shp (Shapefile) format, which was then given an appropriate height using the *Extrusion* tool.

Fig. 5. Integration of the BIM model in a GIS environment (own study)

7. Results

For the analysis, two possible flood situations were simulated for the study area.

1. Flooding due to failure, damage or destruction of damming structure.
2. *Rainfall* flooding using ArcGIS Pro's *rainfall simulation* tool.

For the first simulation, the flood hazard layer created at an earlier stage was used and given an appropriate elevation. The result of the simulation is the intersection of the .shp layer with the BIM model and their height relationship to each other (Fig. 6). The model works entirely with the created water layer, hence it is possible to estimate how the flood also affects the interior of the building. Using the *measure* tool in ArcGIS Pro, it is possible to measure at what height the water is (Fig. 7). The second *simulation* was done using the *simulation rain fall* tool of ArcGIS Pro, which was released in 2024 (Esri, 2024). For these analyses, a rainfall intensity of 470 mm/h, classified as a natural disaster storm, was used (Powiat Żywiecki Klasyfikacje Opadów, n.d.). Simulations were conducted for the first three hours of precipitation (Fig. 8).

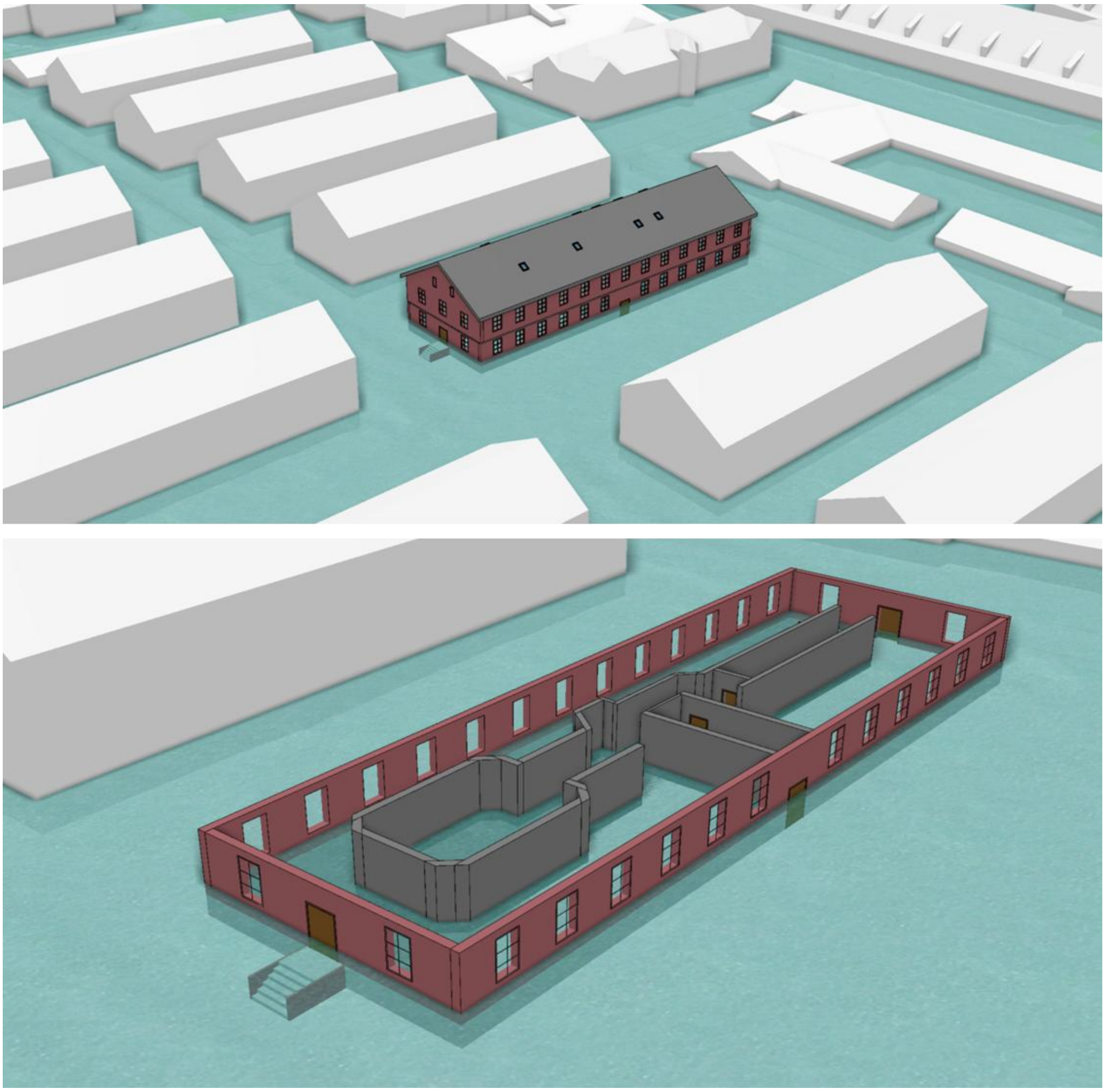

Fig. 6. The result of flood simulation due to failure, damage or destruction of damming structure (own study*)*

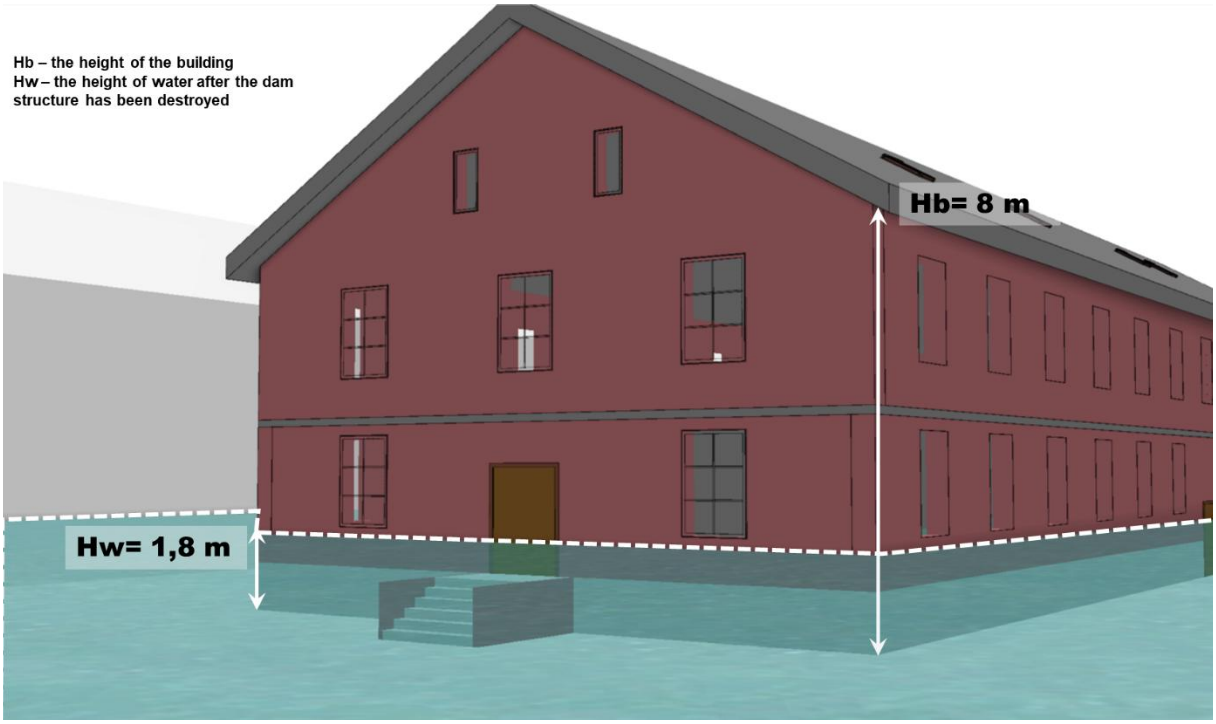

Fig. 7. Height relations between the analyzed building and the flood water level due to the failure, damage or destruction of the damming structure (own study)

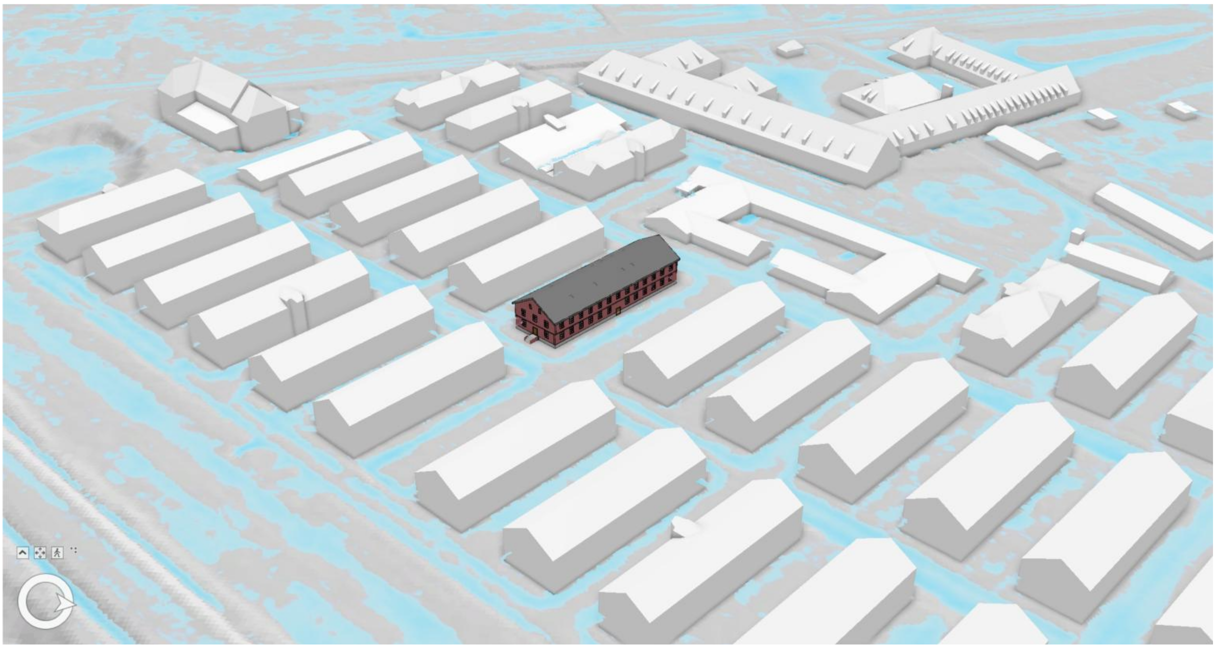

Fig. 8. The result of the flood simulation obtained with the simulation rain fall tool ArcGIS Pro for the parameters of the natural disaster (own study)

8. Estimating losses

Floods pose a direct threat to human life and cause significant material damage (Runkiewicz, and Sieczkowski, 2017). The extent of damage to buildings depends on the duration of flooding, construction technology and the type of building materials used (Bajno et al., 2022). Moisture has a significant impact on the expansion of masonry elements, especially in masonry made of ceramic materials. The phenomenon of swelling of ceramic czerepa accumulates in joints, which are usually filled with mortar. The combination of moisture and the physical properties of the elements can lead to a weakening of the structural performance of masonry. Analyses available in the literature conducted after flood events indicate the occurrence of defects such as damage to load-bearing walls, partition walls and ceilings. Partition walls located in basements and on the first above-ground floors are particularly susceptible to damage, as the substructures of these elements lose stability because of water, which can lead to their deformation or collapse. Moreover, excessive moisture in masonry creates favorable conditions for the growth of fungi and mold (Engel, and Jasieńko, 2003). As a result of water saturation and due to the processes of swelling and shrinking of the material, deformation of wood floors and floors occurs. In addition, door and window woodwork is significantly exposed to damage, which can lead to a loss of their functionality and aesthetic value. In addition to technical damage to the building, flooding can lead to serious damage to historical and cultural assets (Burshe, and Lipkowa, 1968). Building No. 17, located on the Auschwitz I site, currently serves as the location of the Austrian Exhibition (Państwowe Muzeum Auschwitz Birkenau, n.d.). Artifacts such as books, documents, or everyday objects of the time can be damaged by moisture or contact with water. In the case of such objects, repair can be extremely difficult, and in some cases impossible, representing an irreparable loss to cultural heritage (Pawlik, 2003). In the event of a flood, it is recommended that detailed technical expertise be carried out to assess the technical condition of the building's structure, the level of moisture and the condition of the electrical (Stowarzyszenie Międzynarodowych Ekspertów Budowlanych, n.d.). In addition, regarding cultural assets, it may be necessary for qualified preservationists to take action to secure and protect endangered buildings.

9. Discussion and Conclusion

Historical Building Information Modeling (HBIM) is a modern and promising subset in the field of BIM modeling, which enables faithful representation and preservation of buildings of historical and cultural significance. This paper presents the application of BIM and GIS technologies in flood risk analysis for historic buildings, highlighting their importance in the context of cultural heritage preservation. Integrated HBIM models with GIS technology enable detailed simulations, such as flood scenarios, to identify the most vulnerable elements of buildings and plan preventive measures. The results of the study confirm that HBIM models are an indispensable tool in the management of cultural heritage sites. They not only enable visualization and analysis of potential risks but also improve the process of planning conservation and crisis management activities. Creating digital twins of historic buildings allows preserving their documentation in digital form, which is not only durable, but also easy to update, adapt and use in analysis and management of the building. The research presented opens space for further discussion and research on modern methods of historic preservation in the face of climate change. Integrated HBIM and GIS models may become the standard for hazard analysis and heritage management in the future, contributing to better protection of the cultural and historical heritage of mankind.

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