Using GIS for vulnerability assessment of built cultural heritage from the perspective of natural risks. Case study: Municipality of Bucharest

Cornel PĂUNESCU, Florentina-Cristina MERCIU and George-Laurenţiu MERCIU, Romania

Key words: historical monuments, heritage vulnerability, ArcGIS Online, risk management, map of biophysical vulnerability, sustainable development

1. SUMMARY

Awareness of the patrimonial values of the built cultural heritage determined the development of policies for its conservation. In the context of the increasing impact of climate change, the preservation of cultural heritage was designed to reduce the impact on the environment and limit the impact of natural risks. Thus, the planning process brought to the fore the elaboration of cultural heritage conservation tools to respond to the objective to implement sustainable development strategies. The sustainable planning of historical monuments also requires reporting on the natural risks that could lead to the destruction or degradation of cultural assets in order to identify measures for limiting the effects generated by them.

The central area of city of Bucharest was selected as case study, being representative of the valuable heritage buildings, the relatively large number of historical buildings affected by natural risks. The importance of the study results from the high concentration of buildings expertized with seismic risk. The aim of this study is to propose an approach to assessing natural risks that impact historic buildings using Geographic Information System (GIS). In this study, the authors evaluated the vulnerability of historic buildings exposed to natural risks: seismic risk, heavy rains, and droughts.

For the elaboration of the study, several methods were used: the analysis of specialized literature, field campaigns to identify the number of heritage buildings classified as seismic risk, the ArcGis for the representation of types of risks for heritage buildings.

Based on GIS techniques and information collected during field campaigns, data related to the history of the buildings, size, state of conservation were processed to establish a basic spatial database and to build a risk assessment system for the study area.

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2. INTRODUCTION

Climate change and disaster risks generate significant threats to communities and cultural heritage buildings and sites (Aktürk, Hauser, 2025; Clave, 2022; Fereira et al., 2021; Ravan et al., 2023). As climate change intensifies, the frequency and severity of natural disasters increase, heightening the threat to cultural heritage sites (Aktürk, Hauser, 2025; Wei, Han, Lang, 2024). The impact of climate change on world heritage affects it directly through damage caused by extreme weather events and indirectly through increased pressures such as unsustainable use, development pressures, and inefficient management of cultural heritage elements in the context of poor administration, weak land management (Cave, 2022), and rapid urbanization (Erdoğan, Terzi, 2022). It is necessary to establish standards in conservation through best practices for addressing the impact of climate change through planning, adaptation, and strategies to mitigate the effects of natural risks on built cultural heritage (Cave, 2022).

In recent years, more and more studies have explored the assessment of risks generated by disasters and climate change on cultural heritage or the interrelationships between hazards, exposure, and vulnerability (Cacciotti et al., 2024; Ravan et al., 2023). Seismic risk is one of the natural disasters that affect cultural heritage assets (D'Alpaos, Valluzzi, 2020; Kioumarsi et al., 2022; Ravan et al., 2023; Wei, Han, Lang, 2024).

The importance of these studies lies in managing and mitigating the challenges posed by the impact of climate change on buildings and cultural heritage sites: for example, heavy rain, drought, rising temperatures, flash floods (Barille, Gattuso, Genovese, 2024; Cacciotti et al., 2024; Clave, 2022; Ramadan et al., 2022; Orr, Richards, Fatorić, 2021; Ursu et al., 2019; Wei, Han, Lang, 2024), hurricanes, strong winds, landslides, wildfires, heat waves, water stress (Clave, 2022; Ginzarly, Yeshwant Joshi, Teller, 2024), erosion caused by wind action (Barille, Gattuso, Genovese, 2024; Wei, Han, Lang, 2024). Another risk factor increasingly occurring in the context of intensifying effects of climate change is salinization (Esteban Cantillo, Menendez, Quesada 2024; Wei, Han, Lang, 2024). The analysis of the effects of natural risks highlights the specific mechanisms of damage to heritage buildings and how these can be assessed from the perspective of vulnerability. In relation to vulnerability, three terms have been conceived and defined: exposure, sensitivity, and adaptive capacity, which require adaptation for application in heritage systems (Daly, 2014). Exposure is the degree to which an identified heritage value is exposed to climate variations and their associated impacts. This is determined by environmental conditions (both physical and atmospheric) (Daly, 2014, pp. 270-

271). The sensitivity of the built heritage depends on the material properties and the physical condition or integrity of the asset, while, at the system level, environmental or organizational fragility would also be relevant (Daly, 2014, p. 271). Unlike exposure and sensitivity, adaptive capacity is not an inherent quality of the system, and deliberate efforts can be made to increase the ability to limit (or avoid) the impacts of climate change. Thus, adaptive capacity is defined as the ability of a system to adjust to climate change (including climate variability and extremes), to reduce potential damages, to take advantage of opportunities, or to cope with consequences (Daly, 2014).

The vulnerability of a cultural property is strongly influenced by its structural and material characteristics, which dictate how the site will respond to different threats (Ravan et al., 2023). Linked to sensitivity, the biophysical vulnerability of heritage buildings and sites refers to the ultimate impacts of hazards, such as precipitation, floods, and drought, focusing on their scale, frequency, and extent (Singh Jatav 2020 cited by Ginzarly, Yeshwant Joshi, Teller, 2024). Thus, Esteban Cantillo, Menendez, Quesada, 2024 indicates a series of deteriorations of historic buildings as a result of the impact generated by climate change: increased rainfall, combined with a warmer climate, can accelerate the deterioration of materials (e.g., the recession of glass and limestone surfaces); they can also damage historic materials and cause them to expand and contract; precipitation, soil moisture variation, and salt crystallization lead to faster aging of materials, while gases such as sulfur dioxide, nitrogen dioxide, and ozone can create an acidic mixture that accelerates the corrosion process. Other factors include micro-cracking, thermal stress, and erosion caused by wind action (Barille, Gattuso, Genovese, 2024). Masonry buildings are particularly vulnerable to earthquakes because they often exhibit weaknesses due to construction aspects (poor-quality materials, irregular arrangements, inaccurate architectural details, etc.) and lack of maintenance (D'Alpaos, Valluzzi, 2020).

Spatially expressed vulnerability can include aspects of both biophysical and social vulnerability. For example, the quality of housing located in a historic area could be a significant factor in assessing a community's (social) vulnerability to flooding (Ginzarly, Yeshwant Joshi, Teller, 2024). As climate change intensifies, the frequency and severity of natural disasters increase, heightening the threat to cultural heritage sites (Wei, Han, Lang, 2024), sometimes leading to the partial or even total loss of historical monuments (Barille, Gattuso, Genovese, 2024; D'Alpaos, Valluzzi, 2020; Orr, Richards, Fatorić, 2021). On the other hand, the slow and cumulative deterioration of historical monuments caused by daily environmental changes in the context of worsening climate change is considered a progressive risk (Li et al., 2022). The growing number of buildings and heritage sites threatened by these environmental changes represents a significant challenge for their preservation and protection (Wei, Han, Lang, 2024). These threats are often interrelated with the increasing vulnerability of cultural heritage sites, and in addition, they will affect their long-term maintenance and sustainability, posing significant challenges to current conservation strategies and traditional heritage policies. Cultural and natural heritage elements represent tools that can be proactively used to develop and strengthen resilience and mitigate the threats generated by climate change (Cave, 2022).

Understanding the current challenges faced by cultural heritage is particularly important in order to preserve it and pass it on to future generations (Orr, Richards, Fatorić, 2021; Ursu et al., 2019; De Paoli, Di Miceli, Giuliani, 2020) and to ensure the safety of visitors (De Paoli, Di Miceli, Giuliani, 2020).

The conservation of cultural heritage is associated with significant challenges due to its age and the increasing impact of climate change, particularly natural disasters. A more effective approach would be to implement a proactive risk management strategy for natural disasters rather than investing resources solely in post-disaster restoration efforts (Wei, Han, Lang, 2024). Regarding climate change mitigation strategies in the field of cultural heritage, for example, greenhouse gas emissions can be reduced by improving the energy efficiency of historic buildings (Cave, 2022) through renewable energy projects from the restoration stage itself. It is considered that vulnerability analysis plays an important role in assessing and reducing risks and represents a prerequisite for developing proper strategies for climate change adaptation and mitigation that generate positive effects on cultural heritage (Caciotti et al., 2024). Moreover, most studies are mainly focused on identifying potentially exposed objects, and only a limited number of studies apply the entire risk chain and quantify the associated risks for large sets of objects, for example, at the national, continental, or global level (Nobile et al., 2025).

Although there is significant scientific concern given to the conservation of cultural heritage (Fereira et al., 2021), limited actions can be observed regarding its integration into disaster risk management planning (Nobile et al., 2025). While numerous studies focus on the conservation of individual monuments or sites, the broader integration of cultural heritage into the planning process is limited (Nobile et al., 2025). Governments and planners are concerned with including the response to natural hazards associated with climate change in the planning process. At the same time, it would be necessary to include data on social vulnerability in the decision-making process (El-Zein, Ahmed, Tonmoy 2021 cited in Ginzarly, Yeshwant Joshi, Teller, 2024). Given the highly technical nature of analysing the vulnerability of historic buildings from the perspective of natural hazard impacts (Erdoğan, Terzi, 2022), involving experts with knowledge and practical experience in cultural heritage is essential (Ravan et al., 2023). Managing the impact of natural hazards on cultural heritage assets requires the collaboration of specialists from various fields, including physical sciences, social sciences, and humanities, as well as cultural site managers and environmental scientists (Caciotti et al., 2024; Orr, Richards, Fatorić, 2021; De Paoli, Di Miceli, Giuliani, 2020; Wei, Han, Lang, 2024). In recent years, research has also focused on implementing cultural heritage adaptation to help inform and influence policies (Orr, Richards, Fatorić, 2021). Monitoring as a measure to understand the changes recorded by heritage sites forms the basis of adaptive management. Thus, monitoring is included in a system of assessment and review, which allows a continuous process of updating the management plan in line with changing circumstances and an ever-expanding knowledge base (Cave, 2022). The perception of cultural heritage in a risk context should be approached from the perspective of a dynamic and complex resource that provides resilience, as well as a continuously changing interaction between the past, present, and future

(Crowley et al., 2022). The anticipated impacts of climate change on historic buildings and sites should be dynamic and complex.

In recent years, increasing attention has been given to the cartographic representation of cultural heritage sites susceptible to natural hazards at various scales, but there are few studies that focus on quantifying and mapping the associated risks for large sets of sites, for example, at the national, continental, or global level (Nobile et al., 2025). Understanding the potential risks impacting cultural heritage assets is essential to ensure the implementation of appropriate adaptation and mitigation measures (Daly, 2014). Climate change adaptation through measures aimed at reducing vulnerabilities to the adverse and diverse effects of climate change seeks to increase resilience (Aktürk, Hauser, 2025). To understand both the risks associated with natural hazards and the opportunities, it is necessary to analyse the social, political, and cultural contexts in which communities operate, providing a clearer understanding of the threats affecting cultural heritage and its capacities (Crowley et al., 2022). Furthermore, cultural heritage sites have intrinsic value not only for local communities but are part of world heritage, highlighting the importance of addressing flood risks on a large scale, beyond local boundaries, and involving a larger and more diverse number of stakeholders (Nobile et al., 2025).

Although a series of measures regarding the protection of cultural heritage have been proposed in Romania, underfunding of the cultural sector and a lack of experience in reducing the impact of disasters on cultural heritage are noticeable. The aim of this study is to propose an approach to assessing natural risks that impact historic buildings using Geographic Information System (GIS). In this study, the authors evaluated the vulnerability of historic buildings exposed to natural risks: seismic risk, heavy rains, and droughts.

3. METHODOLOGY

3.1. Case study description

The central area of Romania's capital city was selected as case study, being representative of valuable heritage buildings and the relatively large number of historical buildings affected by natural risks such as seismic risk, heavy rains, and drought. The central area of Bucharest includes the historic center and various protected built-up areas (Batiștei, C.A. Rosetti-Maria Rosetti-Popa Petre, Pitar Moș, Bulevardul Lascăr Catargiu, etc.) and covers an area of 603.8 ha. The central area of Bucharest is bounded by Iancu de Hunedoara and Ștefan cel Mare Boulevards and Victoriei Square to the north, extends to Calea Moșilor, Mihai Eminescu, and Tunari streets to the east; to the south, it is bounded by Bulevardul Corneliu Coposu and Splaiul Independenței, and to the west by Știrbei Vodă, Berzei, and Buzești Streets. The study area is characterized by a high stock of heritage buildings and a historic fabric formed between the 18th century and the early 20th century. The large number of historic buildings with multiple heritage values (historical, architectural, cultural, symbolic) provides numerous opportunities for development of the tertiary sector, particularly cultural tourism. From the perspective of conservation and adaptive reuse, most heritage buildings have been partially renovated (a situation mainly encountered in the historic center, where many buildings are repurposed as restaurants or commercial spaces occupying the ground floor and first floor). The upper levels of the buildings are residential, and they are not included in the renovation process, which results in partial preservation and an unsightly appearance of the buildings.

In recent years, especially starting in 2018, at the initiative of the General City Hall of Bucharest, a process of full restoration of heritage buildings in the central area of Bucharest has been launched, but until now the number of restored buildings is not very large. A significant example is the restoration of the former Gabroveni Inn into a cultural center, Arcub, under the supervision of the Bucharest City Hall. In the central area of Bucharest, most of the buildings assessed as having a high seismic risk (308) are concentrated, which also show an advanced state of degradation and considerable age.

3.2. Methods

For the preparation of the study, several methods were used: analysis of specialized literature, field campaigns to identify the number of heritage buildings classified as being at seismic risk, and ArcGIS for mapping the types of risks for heritage buildings located in the central area of Bucharest.

GIS is a useful tool in conserving cultural heritage affected by the negative impact of climate change (Li et al., 2022; Liu et al., 2024; Petrescu, 2007; Wei, Han, Lang, 2024). There is a growing concern for the application of GIS tools in assessing historical buildings or cities and in conducting spatio-temporal analyses of cultural heritage (Spiridon, Ursu, Sandu, 2016) as it represents an appropriate approach in monitoring the condition of historical monuments in areas under the impact of natural hazards. At the same time, GIS techniques provide solutions to central and local authorities responsible for the conservation of cultural heritage based on the integration of geo-referenced data and information processing. Natural processes or hazards are more likely to be predictable depending on suitable scientific and technological means (Ursu et al., 2019).

3.3.Data collection

The first stage in the elaboration of tis study was to make an inventory of the heritage buildings from the central area of Bucharest and create a spatial database using GIS. Many of the buildings in the study area are classified as historical monuments or are included in protected built areas. Data collection was carried out based on documentation, as well as on-site visits: the year of the initial construction, the architectural style, the current state of conservation. Data regarding the number of buildings assessed for seismic risk and emergency categories were collected from the website of the Bucharest City Hall.

3.4.Risks identification and spatial analysis

The authors used Geographic Information Systems (GIS) to create risk assessment maps that determine buildings affected by natural risks (seismic risk) or climatic factors such as humidity generated by rain and high temperatures that affect historic buildings (natural degradation of construction materials, excessive vegetation growth, or fungal infestation). The biophysical vulnerability of historic buildings in the study area was assessed based on field observations and subsequently mapped in GIS.

4.RESULTS

After identifying historic buildings with different levels of seismic risk, they were mapped (Figure 1) to highlight the areas with the highest density of historic monuments in the central area of the capital city.

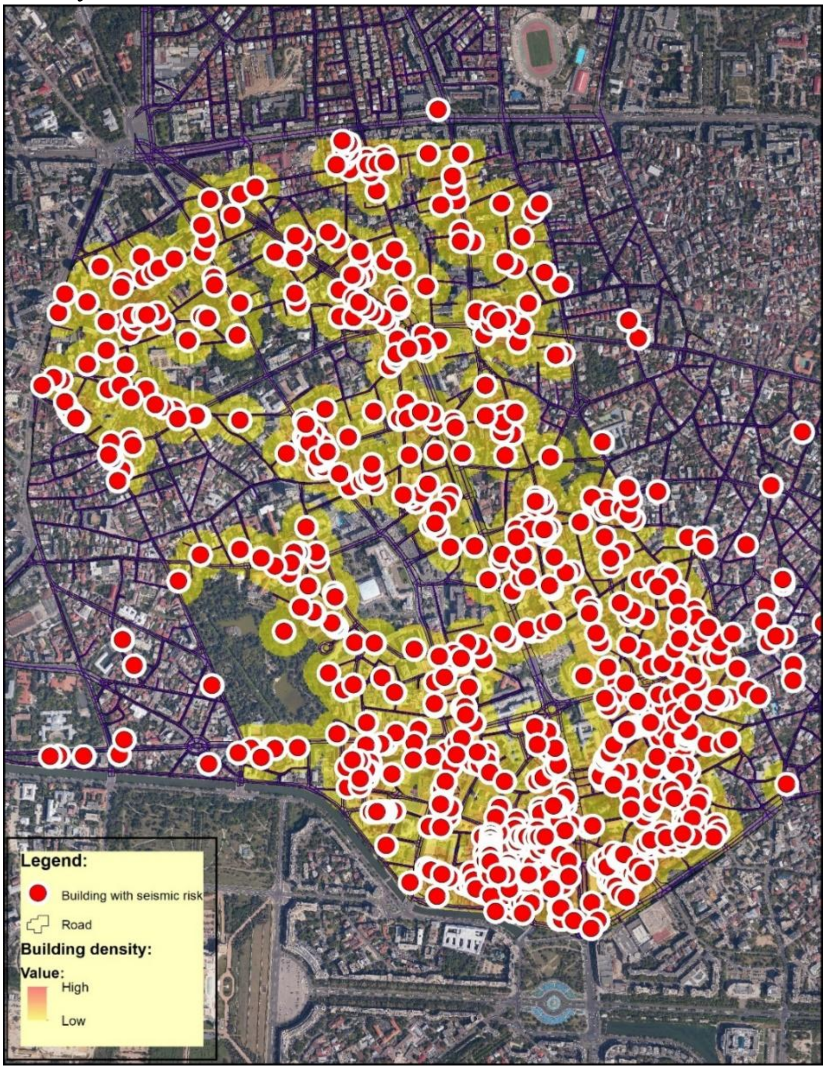

Figure 1. Density of heritage buildings classified with seismic risk by geographical location
Source: own elaboration

The importance of mapping historic monuments classified with seismic risk is related to Bucharest's location in a region with a geological structure prone to intense seismic activity (high-magnitude earthquakes have been recorded, the most recent one occurring in 1977). Earthquakes represent the natural hazard with the most destructive impact on the cultural heritage of Bucharest. It is observed that the density of historical monuments vulnerable to seismic risk, based on their age and low degree of preservation (buildings that have not been restored or reinforced to date), is high in the study area. Within the analysed area, the highest monument density values are found in the historic centre (the southern part of the study area) and in its adjacent area (University Square), as well as in areas located to the north of it (Romană Square) (Figure 1). On the other hand, areas with a lower density of monuments classified as seismic risk, such as Berzei Street, Știrbei Vodă Street, and Grigore Alexandrescu Street, are also noticeable.

For a more detailed analysis of historic buildings classified with seismic risk, their density was also calculated and represented according to their classification by degrees of seismic risk (Figure 2).

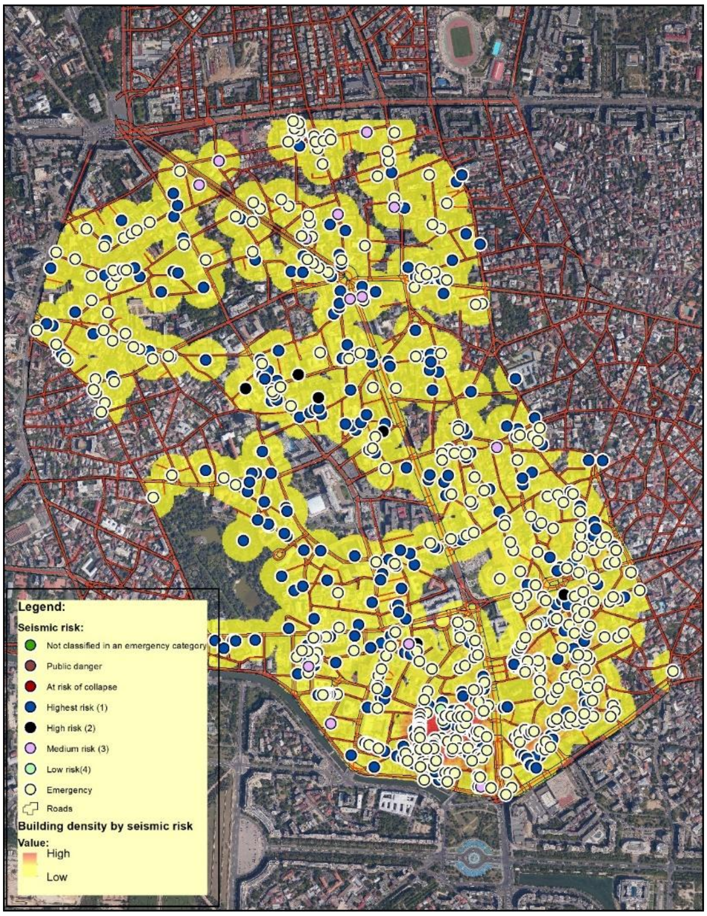

Figure 2. Density of heritage buildings classified by seismic risk according to seismic risk classes

Source: own elaboration

In the central area of Bucharest, there are 5 buildings classified as public hazard, 4 buildings classified as at risk of collapse, 299 buildings classified as risk 1, 6 buildings classified as risk 2, 13 buildings classified as risk 3, and 1 building classified as risk 4. In addition, there are 328 buildings classified as Emergency 1, 26 buildings classified as Emergency 2, and 12 buildings classified as Emergency 3.

During field campaigns conducted between 2022-2025, the biophysical vulnerability of heritage buildings in the central area of Bucharest was evaluated in terms of the impact of rising temperatures and torrential rains, whose frequency has increased in recent years. Based on the assessment carried out through direct onsite observations, the authors identified 4 classes of biophysical vulnerability for heritage buildings (Figure 3).

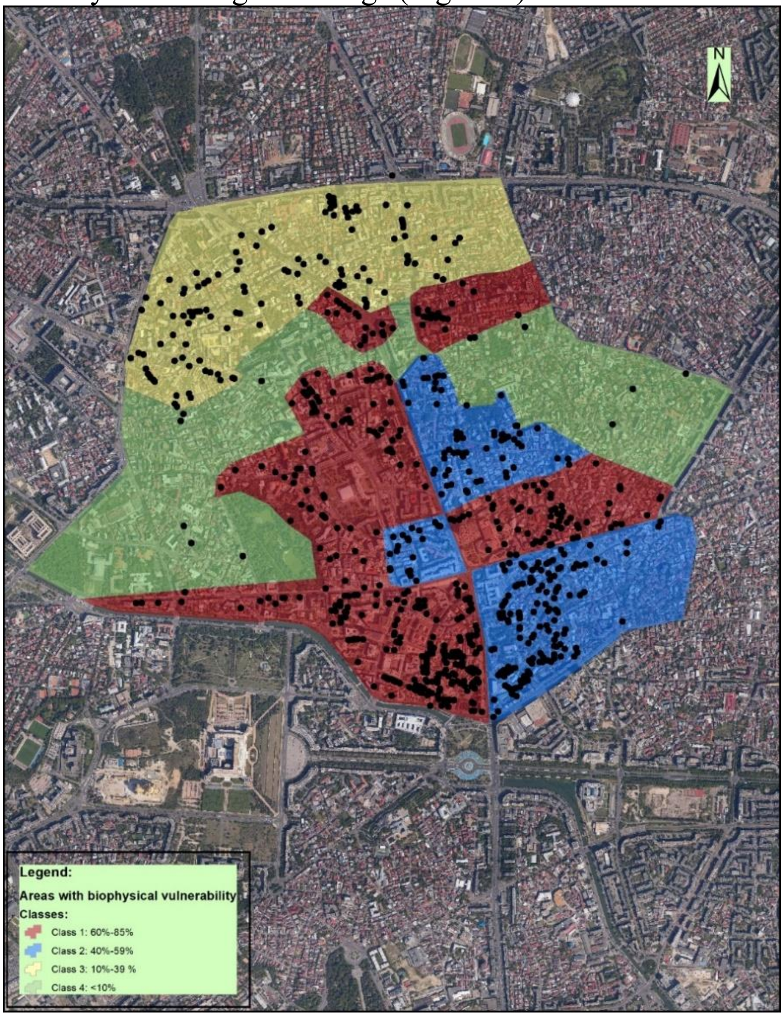

Figure 3. Map of the biophysical vulnerability of historic buildings in the central area of Bucharest due to heavy rain and drought
Source: own elaboration

The highest values of biophysical vulnerability were identified in areas where the largest number of buildings classified in high seismic risk categories (public hazard, collapse risk, risk 1) are located, with values ranging between 60-85%; the second vulnerability class, with values between 40-59%, includes a smaller number of very old buildings (early 19th century), the majority of buildings being constructed in the second half of the 19th century, classified in risk classes 2 and 3 (Figures 3, 4 a, b,c , d). The pronounced physical deterioration of some buildings is also due to their age and the lack of restoration interventions, compounded by the interaction of the constructions with external (climatic) factors. The third class (with values between 10-

39%) and the fourth vulnerability class (below 10%) concentrate most of the buildings listed in Urgency classes 1-3, which exhibit a less advanced state of degradation.

Figure 4. Buildings affected by biophysical vulnerability: facade degradation under the impact of climatic factors can be observed: a) building located at no. 32 Lascar Catargiu Blvd. (2024); b) building located at no. 7 Visarion Street (2024); c) Braikoff House located at no. 2 Georges Clemenceau Street (2023); d) houses with visible symptoms of material deterioration located in the historic centre (French Street) (2025). Photo source: authors

Color alteration has been identified by the authors as a form of deterioration of heritage buildings. Color alteration indicates a change in the color of construction materials applied to building facades, both in hue and in brightness, saturation (Crișan, 2023, p. 205). Hue corresponds to the most prominent characteristic of the color (yellow observed in Figure 4a).

Numerous heritage buildings are affected by material degradation processes as a result of physical actions such as successive expansions and contractions of the mass affected by temperature variations, generating internal stresses (Crișan, 2023). Physical actions produce visible manifestations such as disintegration, erosion, which can lead to the degradation of exterior plasters and missing parts in facade decorative elements made of plaster (Figure 4c).

The process of building deterioration is often accelerated by the lack of maintenance work, which leads to pathological processes of degradation of the plaster and the supporting masonry (in Figure 4b, one can see the presence of rainwater gutters whose lower part has completely deteriorated, and the water that flowed directly onto the building has severely affected the plaster). The missing parts represent deterioration, frequently affecting the prominent and exposed parts of buildings (cornices, balconies) (Figure 4c).

CONCLUSIONS

Cultural heritage is vulnerable to interactions with the environment as a result of the accelerated effects of long-term climate change, as it affects historic buildings through chemical and physical degradation processes. GIS technology is particularly useful for data visualization, spatial analysis, integration with various geospatial data, while also providing decision support and monitoring of the environment and historic buildings. At the same time, GIS is an important and innovative tool for monitoring and mapping, representing an inexpensive means for assessing the vulnerability of historic buildings, spatializing data, and creating relational databases, significantly contributing to the protection of cultural heritage.

The results obtained through GIS-based spatial analysis regarding the assessment of historic buildings in the central area of Bucharest from the perspective of seismic risk and biophysical vulnerability as a result of exposure to climate risks (high temperatures and heavy rainfall) provide details regarding the symptomatology of heritage buildings. These details are useful for urban planners, policymakers, or researchers. Risk assessment has become an increasingly commonly applied methodology in the implementation of planned maintenance and preventive conservation programs, as it facilitates the integration of all available knowledge and the operational efficiency of these efforts.

Future research will focus on developing a WebGIS to highlight the degrees of vulnerability of heritage buildings in the central area of Bucharest, with a dual purpose: to raise community awareness about the impact of risks associated with climate change on historic buildings and to serve as a decision-support tool.

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BIOGRAPHICAL NOTES

Cornel Păunescu is Emeritus Professor PhD. Eng. at the Faculty Geology and Geophysics, University of Bucharest and member of the Romanian Academy of Technical Sciences. st and a member of the Romanian Academy of Technical Sciences. His research areas are: geodesy, topography, GIS, cadastre. He is involved in numerous systematic cadastre projects, obstacle maps for airports, GIS applications for local administrations, cultural heritage, etc.

Florentina-Cristina Merciu is lecturer PhD. at the Faculty of Geography, University of Bucharest, Romania. She is senior researcher Rank 2 at the Interdisciplinary Center for Advanced Research on Territorial Dynamics of the same university. Her research interests include cultural heritage (especially industrial heritage), cultural geography, cultural regeneration, circular economy, etc.

George-Laurenţiu Merciu is associate lecturer PhD. Eng. at the Faculty of Geography, University of Bucharest. His research interests include remote sensing, spatial representation of cultural heritage using GIS tools (including 3D modeling), digital mapping to document and interpret historical sites and buildings, laser scanning. With a background in Geography and GIS with applicability in cadastral measurements, he has contributed to projects involving heritage site mapping, spatial data visualization, GIS solution for the monitoring cultural heritage assets, fostering interdisciplinary collaboration between researchers, policymakers, and local communities.

CONTACTS

Cornel Păunescu
Organisation: University of Bucharest, Faculty of Geology and Geophysics, Romanian Academy of Technical Sciences
Address: Blvd. Nicolae Bălcescu, no. 1, 010410.
City: Bucharest
COUNTRY: ROMANIA
Tel. +40722209287
Email: cornelpaun@gmail.com

Web site:

Merciu Florentina-Cristina
Organisation: University of Bucharest, Faculty of Geography, Department of Human and Economic Geography
Address: Blvd. Nicolae Bălcescu, no. 1, 010410.
City: Bucharest
COUNTRY: ROMANIA
Tel. +40726789190
Email: cristina.merciu@geo.unibuc.ro
Web site: https://unibuc.ro/user/cristina.merciu/

Merciu George-Laurenţiu
Organisation: University of Bucharest, Faculty of Geography, Department of Geomorphology-Pedology-Geomatics
Address: Blvd. Nicolae Bălcescu, no. 1, 010410.
City: Bucharest
COUNTRY: ROMANIA
Tel. +40720585409
Email: george.merciu@yahoo.co.uk