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Research Article

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Urban geoheritage and degradation risk assessment of the Sokograd fortress (Sokobanja, Eastern Serbia)

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Abstract: Sokobanja is a well-known spa centre in East Serbia, whose popularity is mostly based on its natural heritage (thermo-mineral springs, waterfalls, canyons, caves, and pits). However, built heritage also offers significant potential for developing geotourism. This article aims to assess the geoheritage values of the geocultural site Sokograd fortress to support geotourism development in this area. For the assessment of geotourism potentials, the urban geoheritage assessment model (UGAM) was applied. To support the criteria of UGAM (e.g. variety of geodiversity and educational potentials), a macroscopic mineralogical–petrographical observation of the building stone was performed. The results revealed significant educational potentials, especially concerning petrodiversity, with sedimentary rocks (limestone, sandstone, tufa, and conglomerates). By comparing the obtained results with the local geology, it is recognized that the building stone was mainly of local provenance. The UGAM parameters, such as geocultural and ecological values, as well as a variety of geodiversity, confirmed that Sokograd has great potential for urban geotourism development. After all, the assessment of degradation risk was performed and revealed that tourism development cannot cause serious threats to the site, but tourism has to be adequately regulated and managed in a sustainable way. The results of this study can provide information to policymakers, local governments, and other interested stakeholders on whether and how to develop urban geotourism at the Sokograd fortress in the upcoming period.

Keywords: geotourism, urban geoheritage, geoheritage assessment, UGAM, degradation risk

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1 Introduction

Interest in scientific aspects of geoheritage, geoconservation, and geotourism studies has increased, driven by their scientific, academic, cultural, historical, and aesthetic significance. One of the niche fields of modern tourism is urban geotourism, which has gained popularity, both educational and practical, in the past few years [1]. Urban geotourism involves exploring any part of a city, or its surroundings, which showcases geological concepts and features, whether through built heritage or exposed rock formations [2,3]. This emerging form of tourism has garnered scholarly attention in recent years, with researchers noting its novelty [2–10]. Many authors dealt with the definition of the term urban geosite [1–6] and it refers to a site that displays geological processes or man-made structures constructed from characteristic rock types that reveal the geological and geomorphological processes intertwined with urban development.

From a multidisciplinary perspective, urban geotourism offers a platform to share diverse fields of knowledge, including history, geology, palaeontology, archaeology, environment, architecture, science, and tourism [3,11,12]. Participation in urban geotourism activities can be beneficial for enhancing the awareness of geodiversity's significance within urban environments [5], fostering a deeper understanding of the relationship between geodiversity and culture [13].

The historical, cultural, religious, and social values of urban areas are evident, with traditional building materials like natural stone, original outcrops, and construction techniques serving as significant tourist attraction and integral parts of urban geoheritage [14–17]. The geological aspect plays a crucial role in understanding various aspects of urban development, including initial settlement locations, architectural evolution, construction materials, access to mineral resources, water usage, and topographic conditions [18,19]. Some authors [5,20,21] also introduced the notion geocultural sites, which represents sites with high historical and cultural relevance and with strong links to the geodiversity of the area (landscape, use of local materials, water resources, etc.). These sites may include sacral buildings, castles, monasteries, fortresses, ruins, municipal buildings, and artificial caverns. It is not necessary for them to be situated in urban areas, they may be in a rural (open) landscape, and the most important aspect is the close link of geodiversity – culture on the site.

Numerous natural (erosion, weathering, landslides, and earthquakes) and human-induced factors and processes (unregulated tourism, urbanization, infrastructure development, and vandalism) can endanger the integrity of geosites, resulting in their degradation [1,22–27]. Therefore, it is essential to recognize the risks of geoheritage degradation as a crucial aspect of any strategy for geotourism development and geoconservation activities. Brilha [1] highlighted that geosite assessment and degradation risk assessment are very important tools for applying geoconservation actions and preparing geosite management strategies. With these tools, geosite management can establish priorities in action plans. Fuertes-Gutiérrez and Fernández-Martínez [28] offered a comprehensive definition of vulnerability as the susceptibility to destruction resulting from human activity. They delineate sites as vulnerable when intensive human activity impacts them or when their scale is so limited that any human action can lead to damage. Moreover, the authors draw a sharp distinction between vulnerability and fragility, asserting that fragility denotes a site's susceptibility to degradation under prevailing natural conditions, without human intervention. A site is considered fragile when it undergoes either rapid deterioration or destruction at a human scale. Some authors [29–31] reported that inadequately regulated and ineffectively managed tourism could lead to irreversible damage to scientific and historic values of the cultural site (e.g. Petra, Machu Picchu, Angkor, and Pompeii), so tourism should be planned and managed sustainably.

Sokobanja is a well-known spa centre in Serbia, which attracts many tourists throughout the year. Even though its popularity is mostly based on the natural heritage, such as thermo-mineral springs, waterfalls, canyons, caves, and pits [32–34], built heritage also offers significant potential for developing urban geotourism. The area of Sokobanja has been inhabited for centuries (Romans, Byzantines, Ottomans, and Serbs), and numerous cultures have left heritage value remains that possess cultural value, reflecting methods of natural resource exploitations. So, this article aims to estimate the urban geotourism potentials of the geocultural site, Sokograd fortress, located near Sokobanja, by using the urban geoheritage assessment model (UGAM) [35]. This model comprises situational analysis, providing data on the current state and future perspectives of urban geosite, as well as identifying tourist potentials that can be converted to tourist values. Based on the obtained data, the modelling procedure can allow policymakers and all other stakeholders to create strategic frameworks for future tourism development. To support UGAM parameters (e.g. a variety of geodiversity and educational possibilities), the macroscopical petrographical–mineralogical observations of the building stone of Sokograd were performed, to reveal a potential connection with the local geology. In addition, the assessment of degradation risk was applied to set priorities for the future tourism development and management plan. The macroscopical petrographical–mineralogical analysis also identified the building stone of Sokograd and its physical characteristics (hardness and density) and revealed the site's susceptibility to degradation, as most of the building stones of Sokograd (limestone, sandstone, and conglomerates) have higher hardness values according to Ghorbani et al. [36]. This means that these solid rocks have a higher susceptibility to natural and human-induced degradation.

2 Study area

2.1 Geological settings

The Sokobanja basin, situated in the central part of Eastern Serbia (Figure 1), constitutes a complex territorial system extending between the Timok basin in the East and the Moravian basin in the West. It lies within the Carpathian-Balkan region, bordered by the Crnorečki, Svrljiški, Aleksinački, and Knjaževački basins, encompassing an area of 525.5 km^2 [34]. Surrounded by mountains of moderate elevation, the basin is surrounded by the Rtanj Mountain (Mt.) in the North, the Slemen Mt. and Krstatac Mt. in the East, the Bukovik Mt. in the Southwest, the Devica Mt. in the Southeast, and the Ozren Mt. in the South.

The area of East Serbia is primarily characterized by the Carpatho-Balkanides. As a segment of the broader Alpine-Himalayan belt, the Carpatho-Balkanides orogen serves as a notable repository of knowledge regarding sedimentary, deformational, and magmatic occurrence associated with the

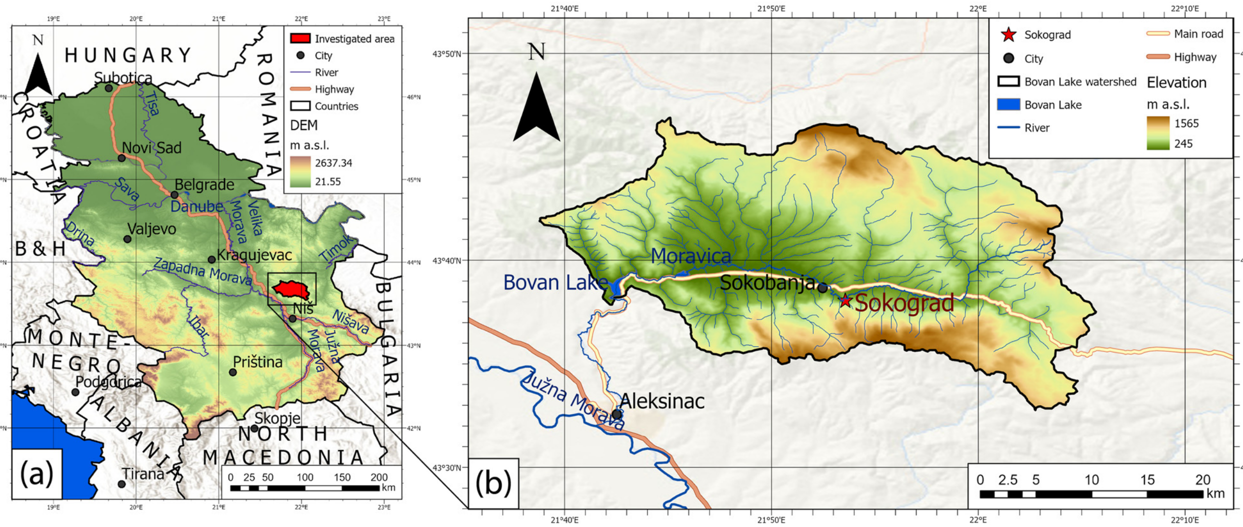

Figure 1: (a) Geographical position of the Sokobanja municipality within the borders of the Republic of Serbia and (b) position of the Sokograd fortress within the Sokobanja municipality.

protracted collision between Africa and Europe [35]. This mountain range is part of the North Alpine mountain range. Carpatho-Balkanides enter Serbia from the East and consist of the younger zone of the Dinaric Mountains.

The geotectonic of the area reveals that the Carpatho-Balkanides are composed of several units, progressing from West to East: the Serbo-Macedonian Massif, the Supragetic unit, the Getic unit, and the Danubian nappes (lower and upper). Each of them is characterized by distinct pre- and early Palaeozoic evolutionary histories. They are likely amalgamated before the late Palaeozoic, subsequently forming a unified geotectonic entity, intruded by Variscan (Carboniferous) plutons and overlain by continental fluvioclastic sediments, such as the Red Permian Sandstone Formation [37–39].

In the period of existence of the Vardar Tethys Ocean, spanning from the Permian/Triassic rift-related ocean opening to the Late Cretaceous subduction and closure, the area of East Serbian Carpatho-Balkanides constituted the active margin of the European plate. The area went through multiphase compression, extension tectonics, and subduction-related magmatism, leading to the formation of the globally recognized andesite copper belt known as the Banatite-Timok-Srednogorie [40,41].

The current geotectonic layout of the area was formed by the latest Mesozoic/earliest Cenozoic collision between Europe and Adria (African promontory). Afterwards, the region has been an east-vergent nappe pile thrust onto the Moesian platform, experiencing post-collisional tectonic activity throughout the entire Cenozoic era [42]. The ending phase of the tectonic evolution of this part of Serbia was in the Savska phase of Alpine orogenesis [34].

The tectomorphogenesis of the Sokobanja basin is notably convoluted, owing to its extensive geological history marked by intense tectonic activity, particularly during the Tertiary period. This complexity is evident in the relief, characterized by numerous faults and fault zones cutting across geological formations in various directions. The Sokobanja fault, spanning 17 km along the southern rim of the basin, stands out as the dominant tectonic feature [43]. The basin's geological formations, reflecting its complex tectonic evolution, encompass a variety of rock types and genesis (Figure 2). Predominant among these are sedimentary formations, crystalline schists, and volcanic rocks, with estimated ages exceeding a billion years [44].

In Figure 2, it can be noted that Neogene sediments are dominant in the lowlands of the basin, while Quaternary sediments are located in a narrow belt around the Moravica River and its bigger tributaries. All Paleogene rocks are located in the Northwest part of the basin, relatively far away from Sokograd. The fortress itself is located on Cretaceous limestones.

In the western part of the basin, Tertiary deposits of weakly metamorphic Proterozoic schists are prevalent, particularly on the Bukovik and Rožnje Mt. Near the village of Resnik, carbonaceous formations, including conglomerates, quartz sandstones, and clays, with thin coal layers are found. Permian red sandstones, laminated limestones, and dolomites are also present in the western region. The northern, southern, and eastern parts of the Sokobanja basin are predominantly composed of Mesozoic complex deposits. The mountains of Rtanj, Krstatac, Devica, Ozren, and Leskovik consist of Upper Jurassic oolitic banked and

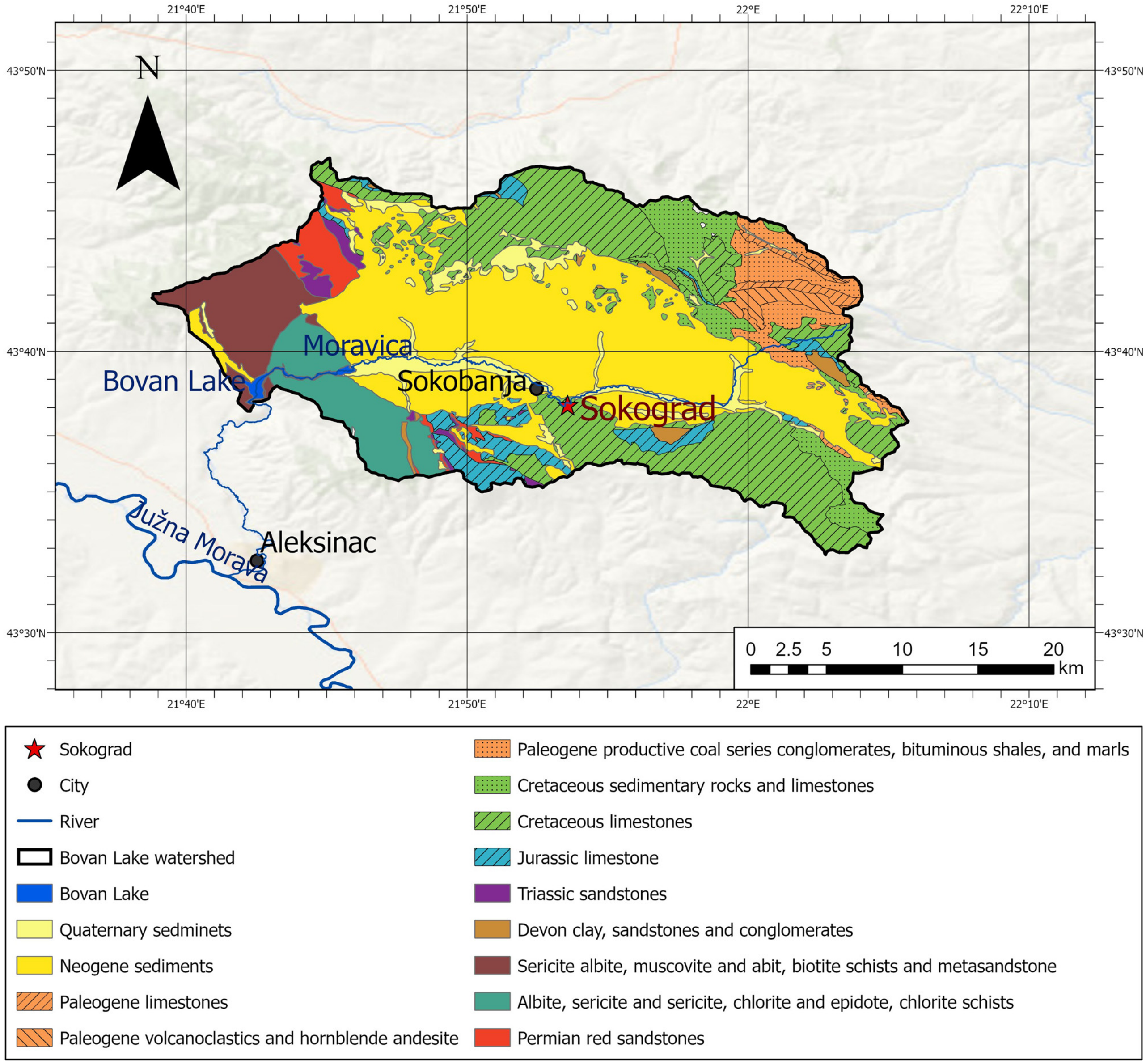

Figure 2: Simplified geological map of the surrounding area of Sokobanja municipality [37,44,45].

layered limestone and dolomite. Additionally, Paleozoic deposits in the form of Devonian fine-grained sandstones, thin layered phyllites, and argillaceous rocks are found in the northern part of the Sokobanja basin [44,45].

Sokograd is a former fortified city, built after the conquest of this area by the Romans (Figure 3). It is located on a high limestone cliff above the Moravica River near Sokobanja. The Sokograd fortress is situated on the 65 m high Miocene river terrace, the limestone mass of Mt. Ozren, in the Sokograd canyon of the Moravica River (Figure 4). The mountain massif of Ozren is built of Upper Jurassic oolithic bank and stratified limestones and dolomites [34]. Below the Sokograd, the Moravica River cut the edge epigeny in the limestone mass of Mt. Ozren.

2.2 Archaeological background

The Sokograd fortress, also called *Sokolac*, represents a medieval fortress located 2 km East of Sokobanja. Recognized as a Monument of Culture of Great Importance in 1982, this fortress is under the protection of the Republic of Serbia [46]. Its origin dates back to the sixth century from the period of Eastern Roman Emperor Justinian I, built to

Figure 3: (a) Panoramic view on the Sokograd fortress and (b) entrance gate of the Sokograd fortress.

defend against the invasion of Pannonian Avars and Slavs of the Balkan Peninsula. Roman aqueduct and water pipes were founded and the site advocated that the Romans built an original fortification on that location [34]. The original fortification was built on a bedrock composition that should support the building material (limestone mass), and the limestone ridge was difficult to reach by the invaders.

In 1172, it came under the control of the Serbian ruler Stefan Nemanja, becoming a crucial stronghold of the Serbian state from the medieval ages. During the expulsion of the Bogomils from Serbia, Stefan Nemanja had a confrontation with the Bogomils. The Ottoman Empire seized the fortress in 1398, devastating the town in a violent attack [47]. Today, only remnants of the upper town are visible, including a gate, walls, and towers.

Sokograd, meaning "falcon city," got its name from the numerous falconers who lived there, paying taxes with their trained falcons. The primary Justinian's fortification consisted of the citadel perched atop the highest point of the limestone ridge, making it nearly impregnable. As the Serbian state prospered, the fortification expanded around the main tower, sprawling down the ridge. At its core, the citadel featured a prominent main tower, with bulwarks extending towards the Moravica River, forming the Lower town on a more accessible terrain. Although the complex once brimmed with several towers, only a few remain today. The first entrance tower in the Upper town remains remarkably intact, while others are in ruins, recounting stories of past times [47].

3 Methodology

Many research studies point to geoheritage assessment as an important step for its promotion or creation of a

Figure 4: Panoramic view from the highest tower of Sokograd on the surrounding area.

geoconservation strategy and an educational programme [1,48,49]. The main purpose of the assessment process is to identify the value of geoheritage using a set of criteria, which will identify areas of interest and regulate their sustainable use [15,50,51]. The methods for the assessment of geosite, both quantitative and qualitative, are constantly developing, and most of them deal with scientific, educational, aesthetic, tourism, and other values [52–63].

3.1 UGAM method

This article aims to assess the urban geotourism potential of the medieval fortress of Sokograd, so the UGAM developed by Marjanović et al. [35] was applied. Along with that, as a complement to the assessment of a site's value, the assessment of the degradation risk proposed by Brilha [1] was performed to propose sustainable use of the geoheritage elements of the site. The macroscopical petrographical–mineralogical analysis was performed to reveal information about the building stone of Sokograd and to support some parameters of UGAM (such as a variety of geodiversity and educational possibilities). This analysis should also provide information about possible degradation risks of the site due to tourism development, such as the durability of the building stone and its resilience to human impact.

The UGAM is a blend of various existing geoheritage assessment models, tailored for the specific requirements of urban geoheritage evaluation. It comprises two main categories of value indicators: urban geosite value (UGV) and tourism value (TV). The UGV consists of 13 subindicators, while the TV encompasses 12 subindicators. Each subindicator can be rated on a scale from 1 to 5 (Table 1).

After assessing the site and analysing the results, a matrix of UGV and TV will be constructed. In this matrix, the *X*-axis represents UGVs, while the *Y*-axis represents TVs. The matrix consists of 25 fields, denoted as $U(i, j)$, where (i, j = 1, 2, 3…). Each site is positioned within the matrix based on its respective values. For instance, if a site has an UGV of 110 and a TV of 190, it will be placed in field U_{33}. These data illustrate the significance of a geosite within a specific area, as well as the relationships between its UGV and TV. Marjanović et al. [35] conducted a survey as part of their research on the urban geotouristic segment. They calculated the importance factor (Im) for each subindicator in the UGAM specifically concerning Serbian tourists. The importance factor values used in this study

Table 1: Structure of UGAM values

	Indicators	Subindicators	Description of criteria			
UGVs	Scientific values (SVa)	Representativeness ($SIUGV_1$)	The characteristics of the site itself; the level of processes or elements of geodiversity that can be observed on site compared to the ideal example			
		Rarity ($SIUGV_2$)	Number of similar localities within the researched area			
		Paleo significance ($SIUGV_3$)	The possibility of presenting paleogeographical elements or processes; reconstruction of relief, climate, and distribution of organisms and organic matter (paleoclimatology, paleobiogeography, paleogeomorphology, paleoglaciology, paleoecology, and paleovolcanology)			
		Geohistorical values ($SITV_4$)	The link between geodiversity and site history; the importance of geodiversity characteristics for urban spatial development and its ability to stimulate a connection with the past			
		Geocultural values ($SITV_5$)	The cultural connection of the site with geodiversity, anthropogenic forms of relief, and the use of built materials and techniques in the construction of a local or regional character or a wider area			
		Ecological values ($SITV_6$)	Presence of specific or rare species, important, or endangered ecosystems			
	Natural values (NVa)	Aesthetic values ($SIUGV_7$)	Visual attractiveness of the site, colour contrast, structure of the surrounding area, and attractiveness of the panoramic view			
		Variety of geodiversity ($SIUGV_8$)	The number of different forms of geodiversity in the locality (geological, geomorphological, hydrological, speleological, and paleontological.)			
		Surface ($SIUGV_9$)	Total surface of the site; each site is quantitatively compared with other valued sites.			
	Protection (PVa)	Integrity ($SIUGV_{10}$)	Current state of the site, degree of damage, and state of representative elements of geodiversity			
		Protection ($SIUGV_{11}$)	Level of site protection			
		Threats to the site ($SIUGV_{12}$)	Possible threats to geodiversity; risks and hazards (anthropogenic and natural)			
		Carrying capacity ($SIUGV_{13}$)	The maximum number of visitors to the site, whose presence will not damage the current state of the site and reduce its visual quality			
TOURIST VALUES (TV)		Education ($SITV_1$)	The possibility of interpretation and the possibility for people without geological knowledge to understand the elements and processes			
		Accessibility ($SITV_2$)	The possibility of reaching the locality			
		Visitor safety ($SITV_3$)	The ability of visitors to move safely throughout the site (danger of landslides, slippery surface, safety fence, and proximity to busy traffic)			
		Visibility ($SITV_4$)	The level of visibility of the specificity of geodiversity, the position of the geosite concerning the viewpoint or path, the number of viewpoints, the vegetation around the geosite, and the discovery of the geosite			
		Promotional activities ($SITV_5$)	Quality and diversity of promotional activities			
		Number of visitors ($SITV_6$)	Number of visitors during the year			
		Information boards ($SITV_7$)	Number and quality of information boards (quality of textual and illustrative content, display of content in colour, multilingual interpretation, and materials in harmony with nature)			
		Tourguide service ($SITV_8$)	Quality of interpretation, level of expertise, and multilingual interpretation			
		Information centre ($SITV_9$)	Proximity to the information centre (tourists and visitors)			
		Tourist infrastructure ($SITV_{10}$)	Footpaths, rest areas, waste disposal areas, toilets, and paths for people with disabilities			
		Accommodation ($SITV_{11}$)	Proximity to accommodation facilities			
		Restaurant services ($SITV_{12}$)	Proximity to restaurant facilities			
Values (1–5)		**1**	**2**	**3**	**4**	**5**
$SIUGV_1$	Representativeness	Not representative	Low	Medium	High	Very high
$SIUGV_2$	Rarity	Usual	Local	Regional	National	International
$SIUGV_3$	Paleo significance	None	Low	Medium	High	Very high

(Continued)

Table 1: *Continued*

	Indicators	Subindicators	Description of criteria			
$SIUGV_4$	Geohistorical values	None	Low	Medium	High	Very high
$SIUGV_5$	Geocultural values	None	Low	Medium	High	Very high
$SIUGV_6$	Ecological values	None	Low	Medium	High	Very high
$SIUGV_7$	Aesthetic values	None	Low	Medium	High	Very high
$SIUGV_8$	Variety of geodiversity	Only 1	2–3	4–5	6–7	8 and more
$SIUGV_9$	Surface	Small	Small/Medium	Medium	Medium/Large	Large
$SIUGV_{10}$	Integrity	Totally destroyed, with no possibility of reconstruction	Mostly destroyed, with the possibility of reconstruction	Partially destroyed	A little ruined	Not destroyed
$SIUGV_{11}$	Protection	None	Local	Regional	National	International
$SIUGV_{12}$	Threats to the site	Very high level of threats (constant anthropogenic pressure that can lead to the total destruction of geodiversity); there is no protection plan	High level (frequent anthropogenic pressure); there is a plan for partial pressure reduction	Medium level (occasional anthropogenic pressure, small possibility of natural disasters); there is a plan to reduce the pressure if it happens	Low level (possibility of natural disasters), there is a plan for their reduction	There are no serious threats to the site (anthropogenic and natural)
$SIUGV_{13}$	Carrying capacity	1–10	11–20	21–30	31–40	over 41
$SITV_1$	Education	None (phenomena and processes are poorly developed and not suitable for education)	Low (phenomena and processes are difficult to understand even with an expert guide)	Medium (phenomena and processes are understandable but with an explanation by a professional guide)	High (phenomena and processes are understandable with the help of an info board, map, and written or audio guides)	Very high (phenomena and processes are easy to understand even without additional interpretive content)
$SITV_2$	Accessibility	Difficult to access (accessible with special equipment)	Accessible on foot	Accessible by bike	Accessible by car	Accessible by mini-bus, tourist bus
$SITV_3$	Visitor safety	It is not safe to be on the site (active processes of landslides and landslides), the possibility of visiting at your own risk	Low level of security; there are frequent threats to the safety of visitors, but the movement around the site is possible with a special permit and equipment	Medium level of security; there are threats to the safety of visitors, but the movement around the site is possible with compliance with the rules; not suitable for larger groups; close to a heavy-traffic street	High level of security, there are small threats to the safety of visitors, but their existence does not represent a potential risk; no heavy-traffic streets nearby	It is completely safe, there are no threats to the safety of visitors
$SITV_4$	Visibility	Very hard to see	Low visibility; partial exposure of the site (visible from only one angle – 1 viewpoint)	Medium visibility; clearly visible from two angles (2 viewpoints)	High visibility, clearly visible from three angles (3 viewpoints)	Full visibility, clearly visible from 4 and more angles
$SITV_5$	Promotional activities	None	Local	Regional	National	International
$SITV_6$	Number of visitors	Random visitors (0–50)	Low (51–10,000)	Medium (10,000–50,000)	High (50,001–100,000)	Very high (over 100.000)
$SITV_7$	Information boards	None	Low	Medium	High	Very high
$SITV_8$	Tourguide service	None	Low	Medium	High	Very high
$SITV_9$	Information centre	More than 50 km	10–50 km	10–5 km	5–1 km	Less than 1 km

(Continued)

Table 1: *Continued*

	Indicators	Subindicators	Description of criteria			
$SITV_{10}$	Tourist infrastructure	None	Low quality	Medium quality	High quality	Very high quality
$SITV_{11}$	Accommodation	Over 50 km	20–50 km	20–10 km	10–5 km	Less than 5 km
$SITV_{12}$	Restaurant services	Over 15 km	15–10 km	10–5 km	5–1 km	Less than 1 km

were adopted from their research article. A comprehensive overview of the UGAM can be found in the work of Marjanović et al. [35].

3.2 Macroscopical mineralogical-petrographical analyses: Samples and procedures

Macroscopic observations were employed to define the primary mineralogical and petrographical characteristics of building stones used for the Sokograd fortress. The term "building stone" refers to the stone that is used for construction of the fortress (e.g. towers and walls). These observations focused on attributes such as colour, mineral composition, and fabric, enabling accurate identification of rock types. The tests included visual inspection with the naked eye and a magnifying lens, assessing the relative hardness of the constituents by scratching them with a fingernail, brass coins, and glass (according to the Mohs scale). The sample comprises four rock types recognized as building stone materials at the Sokograd fortress. The aim was not to observe all the types and varieties of building stones at the site. Alternatively, the focus was on stones that display significant macroscopic diversity and are easily available and recognizable for their potential TV – particularly those building stones visible at the Sokograd fortress.

3.3 Degradation risk assessment

For the assessment of the degradation risk, a set of quantitative criteria proposed by Brilha [1] were applied. This method is based on previous methods for degradation risk assessment developed by various authors [64–70] and comprises five main criteria: deterioration of geological elements, proximity to areas/activities with potential to cause degradation, legal protection, accessibility, and density of population (Table 2).

Each criterion is rated on a scale of 1–4 points (where 1 means the worst case scenario and 4 means the best case scenario), and each score is multiplied with the criterion weight (Table 3). The overall degradation risk value is then calculated by summing the scores assigned to each criterion. The final result will classify the degradation risk as low, moderate, or high (Table 4). A site faces heightened risk of degradation when key geological features are highly susceptible to damage, whether from natural phenomena or human activities. Additionally, the absence of legal protection amplifies this risk. Furthermore, proximity to areas with high levels of potentially harmful activities exacerbates the threat to the site's integrity.

Table 2: Criteria, indicators, and parameters used for the quantitative assessment of degradation risk of sites

Criteria/indicators		Parameters
Deterioration of geological elements: reflects the possibility of loss of geological elements in the site as a consequence of (i) its fragility, namely, its intrinsic characteristics (size of the geological element, ease of obtaining samples, resistance of the rock, etc.) and natural actions (susceptibility to erosion, intensity of erosional agents, etc.) and (ii) its vulnerability to anthropic actions (tourism, agriculture, urban development, vandalism, etc.)	Possibility of deterioration of all geological elements	4 points
	Possibility of deterioration of the main geological elements	3 points
	Possibility of deterioration of secondary geological elements	2 points
	Minor possibility of deterioration of secondary geological elements	1 point
Proximity to areas/activities with potential to cause degradation: mining, industrial facilities, recreational areas, roads, urban areas, etc.	Site located less than 50 m of a potential degrading area/activity	4 points
	Site located less than 200 m of a potential degrading area/activity	3 points
	Site located less than 500 m of a potential degrading area/activity	2 points
	Site located less than 1 km of a potential degrading area/activity	1 point
Legal protection: related to the location of the site in an area with any type of legal protection (direct or indirect). Access control refers to the existence of obstacles, such as restrictions by the owner, fences, need to pay entrance fees, mining activities, etc.	Site located in an area with no legal protection and no control of access	4 points
	Site located in an area with no legal protection but with control of access	3 points
	Site located in an area with legal protection but no control of access	2 points
	Site located in an area with legal protection and control of access	1 point
Accessibility: reflects the conditions of access to the site for the general public (not considering disabled people). A site with easy access is more likely to be damaged by visitors' misuse than one with difficult access	Site located less than 100 m from a paved road and with bus parking	4 points
	Site located less than 500 m from a paved road	3 points
	Site accessible by bus through a gravel road	2 points
	Site with no direct access by road but located less than 1 km from a road accessible by bus	1 point
Density of population: reveals the number of persons that live near the site and that can cause potential deterioration to the site due to inappropriate use (vandalism, theft, etc.).	Site located in a municipality with more than 1,000 inhabitants/km^2	4 points
	Site located in a municipality with 250–1,000 inhabitants/km^2	3 points
	Site located in a municipality with 100–250 inhabitants/km^2	2 points
	Site located in a municipality with less than 100 inhabitants/km^2	1 point

4 Results and discussion

4.1 Mineralogical-petrographical characteristics of building stones

The analysed samples of the building stone used for the Sokograd fortress are classified as sedimentary rocks. They are composed of limestone, sandstone, tufa, and conglomerates. *Limestone* is found as a building stone for defensive walls (Figure 5b). The samples have clay-sized grains and a fine-grained texture. They are grey in colour, with no

Table 3: Weights for different criteria used for the assessment of degradation risk of sites

Degradation risk	
Criteria	**Weight**
A. Deterioration of geological elements	35
B. Proximity to areas/activities with potential to cause degradation	20
C. Legal protection	20
D. Accessibility	15
E. Density of population	10
Total	100

Table 4: Degradation risk level

Total weighted	Degradation risk level
<200	Low
201–300	Moderate
301–400	High

visible traces of fossils. *Sandstone* is found as a building material for the inner tower (Figure 6b). The observed samples have sand-size visible grains, are well sorted, have a gritty texture, and they are brown to yellow and grey in colour. *Tufa* is located on the inner tower (Figure 6a). The samples have a friable texture, a spongy structure full of holes, and soft fabric. They are yellow to white and buff in colour. There are visible macro-biological components such as plant stems, grasses, and mosses. *Conglomerate* is found as a building stone of defensive walls and entrance tower (Figure 5a). The rocks in the observed samples are smooth and rounded, with the grain size of pebbles and cobbles. The samples are poorly stratified and brown to reddish in colour. All of these refer to local geology, and the utilization of local stone outcrops, as these rock types are widely spread and easily accessible in the surrounding area (Figure 2) [44,45]. Also, the characteristics of building stones used for the Sokograd fortress (limestone, sandstone, and conglomerates) refer to durable materials and high resistance to natural and human impacts [36].

The petrographic characteristics of the building stones at the Sokograd fortress suggest several aspects that could enhance the site's appeal from a geotourism perspective. The site has significant petrodiversity, encompassing a range of petrographic types, which influenced the scoring of natural value indicators of the UGAM. Additionally, the area's geotectonic evolution and the relationship between the local geology and the building materials (provenance)

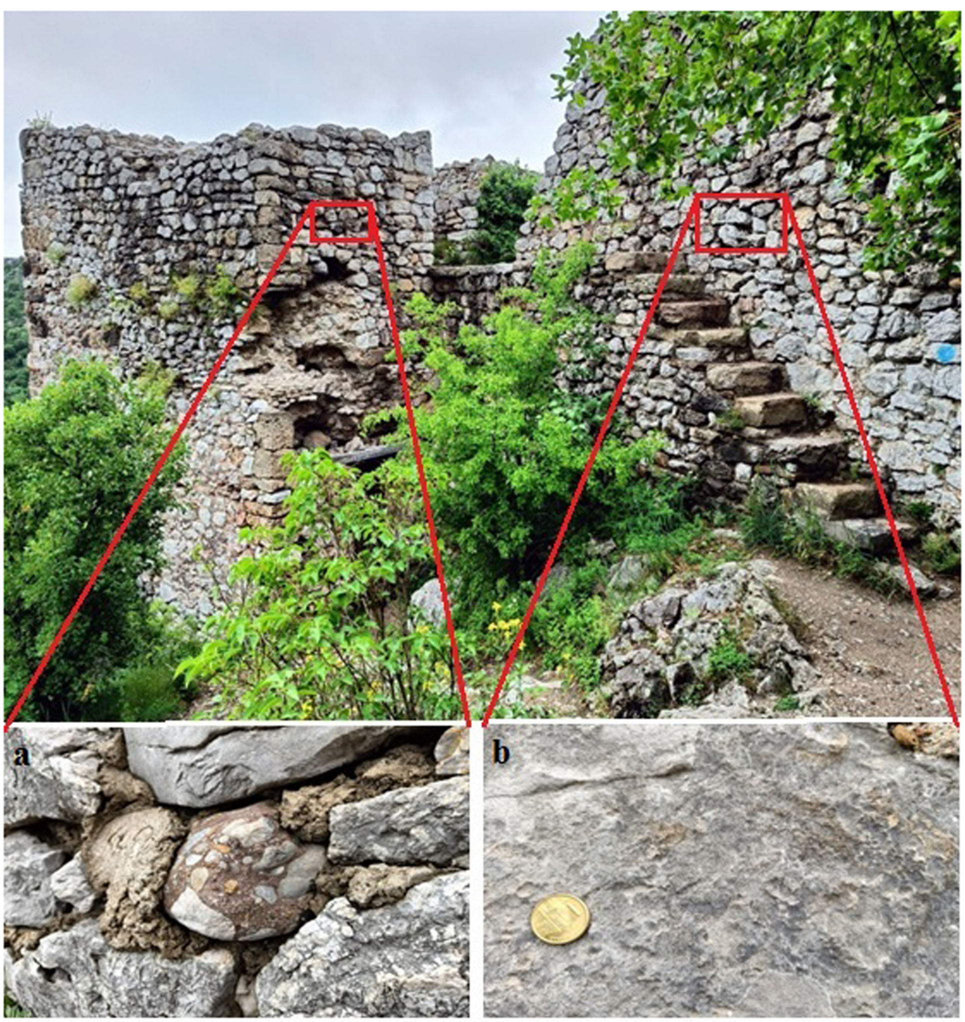

Figure 5: Main building stone visible on the site: (a) conglomerates built in the entrance gate and (b) limestone blocks used for the defensive walls.

Figure 6: Building stone material used for the entrance gate: (a) tufa blocs with visible macro-biological components and (b) sandstone blocks used for the defensive tower.

are notable. This information should be integrated into current archaeological interpretations and further urban geotourism development. This information also influenced the scoring of the geohistorical value subindicator of the UGAM, as it reflects the link between the geodiversity and site history; the importance of geodiversity characteristics for urban spatial development and its ability to stimulate connection with the past.

The results indicate that the petrodiversity at the Sokograd fortress includes sedimentary (limestone, sandstone, tufa, and conglomerate) rocks. The genesis of these rocks can serve as an introduction to geological processes, as inferred from the mineralogical and petrographic features (texture and fabric) of the studied rocks and their physical characteristics (hardness and density). Some rock types (e.g. sandstone) can be presented as an outdoor museum, displaying the history of their formation. The cracks on it can reveal where the sand dried out in the Sun, and bedding marks can reveal the way sand deposition changed continually period by period. These findings helped in the evaluation of the educational possibilities' subindicator of the UGAM. This geocultural site holds value for geoscience research and education. Also, it can serve as an educational resource to illustrate fundamental geomorphological concepts to university students studying geology and geography. There are various types of research highlighting the interpretation of geoheritage (e.g. building stone), referring to rock types used as the construction material, their genesis and provenance, as well as exploitation methods, fossil presentation, characteristics (texture and structure), their use in construction, and architecture [2,17,19,35,71,72]. The interpretation could be implemented in educational geotrails [35], geocultural routes [73], or geoeducational workshops on-site to disseminate the Earth Science to the wider public [18].

4.2 UGAM analysis

The research findings are summarized in Tables 5 and 6, along with Figure 7. Analysis of the total UGAM score suggests that UGVs (137.47) and TVs (129.08) are at a moderate level, indicating that the site falls within the field U_{33}. While Sokograd undeniably has natural values conducive to the dissemination of geoscientific knowledge, they have yet to be sufficiently enhanced to establish it as a recognizable geotourism destination.

Table 5: Subindicator values given by authors for the Sokograd fortress site

Subindicators		Values given by the authors	Im	Total values
		UGVs		
Scientific values				
$SIUGV_1$	Representativeness	2	**3.94**	7.88
$SIUGV_2$	Rarity	2	**3.52**	7.04
$SIUGV_3$	Paleo significance	3	**3.14**	9.42
$SIUGV_4$	Geohistorical values	3	**3.78**	11.34
$SIUGV_5$	Geocultural values	4	**4.00**	16.00
$SIUGV_6$	Ecological values	4	**3.58**	14.32
Natural values				
$SIUGV_7$	Aesthetic values	2	**4.36**	8.72
$SIUGV_8$	Variety of geodiversity	4	**2.87**	11.48
$SIUGV_9$	Surface	2	**2.45**	4.9
Protection				
$SIUGV_{10}$	Integrity	2	**3.78**	7.56
$SIUGV_{11}$	Protection level	4	**4.14**	16.56
$SIUGV_{12}$	Threats to the site	3	**3.25**	9.75
$SIUGV_{13}$	Carrying capacity	4	**3.07**	12.28
		TVs		
$SITV_1$	Education	5	**4.31**	21.55
$SITV_2$	Accessibility	2	**2.74**	5.48
$SITV_3$	Visitor safety	2	**3.09**	6.18
$SITV_4$	Visibility	4	**3.83**	15.32
$SITV_5$	Promotional activities	3	**2.69**	8.07
$SITV_6$	Number of visitors	2	**2.83**	5.66
$SITV_7$	Informative boards	1	**4.00**	4.00
$SITV_8$	Tourguide service	1	**4.07**	4.07
$SITV_9$	Information centre	4	**3.69**	14.76
$SITV_{10}$	Tourist infrastructure	2	**4.12**	8.24
$SITV_{11}$	Accommodation	5	**3.43**	17.15
$SITV_{12}$	Restaurant service	5	**3.72**	18.6

Bold values represent values of Importance factors for Serbian tourists in UGAM model. They are bold just for visual separation from other values.

4.2.1 UGVs

The evaluation of UGV subindicators offers insights into the current state of the site and its potential for urban geotourism development. Although its scientific values are somewhat diminished by low rarity and representativeness, the site still retains basic values despite significant degradation. This site has a local level rarity. However, it does not demonstrate the absence of heritage value, but the

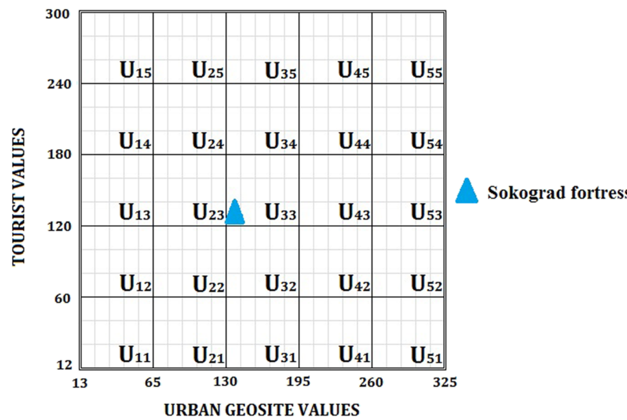

Figure 7: Position of the Sokograd fortress in the UGAM matrix.

value is not large. The Sokograd fortress stands out due to its unique spatial–visual relationship with the surrounding area. Additionally, the site offers an attractive panoramic view of the Sokograd gorge and its surroundings. Visitors can enjoy the local landscapes, prominently featuring the mountains, gorges, caverns, and cuestas, which are easily visible from numerous observation points, reflecting the aesthetic properties of the site. Paleo significance of the site is not rated with a high score. However, there are some features important for paleo interpretation (Miocene river terrace, fossil flora, and sandstone surface). The geocultural values are rated as high. It has remnants of Roman, Byzantine, Ottoman, and Serbian cultures, showcasing the synergy between geography and human presence, along with the use of local materials in construction. The cultural value of the site is related to its name "Sokograd" (falcon fort) as this area is famous for being the training ground for the falcons in ancient times. The municipality of Sokobanja also got its name after the Sokograd. The Sokograd is linked with many historical tales, myths, and legends which attract many tourists to the site, contributing to its value. As a landmark of the city, Sokograd holds relatively high geocultural value, depicted on postcards, souvenirs, and paintings. The building materials sourced from local quarries and the construction style adapted to the area's characteristics add to Sokograd's aesthetic value. The rich geodiversity in the vicinity of the site, including numerous small caves and pits, thermal and mineral springs, and the Moravica River with its falls and rapids, contributes to its high rating by the

Table 6: Overall values of the Sokograd fortress by UGAM

		Values			Position in the UGAM matrix
Urban geosite	UGVs SVa + NVa + PVa	ΣUGV	TVs	ΣTV	Field
Sokograd	66.22 + 25.1 + 46.15	137.47	129.08	129.08	U_{33}

model. These features attract many tourists, nature lovers, but also adventure lovers and climbers. Furthermore, the site boasts a rich petrographic diversity, crucial for Earth Science dissemination. Despite being mostly in ruins, the Sokograd fortress maintains relatively high protection values, especially in terms of subindicators *level of protection* and *carrying capacity*, earning its place on the Serbian Cultural Heritage list. The authenticity of the site and its size attract many visitors during the year without causing significant damage, thus receiving a high value in the model. The site got a medium score for the subindicator *threats to the site*, as there is a small possibility of a natural disaster. The site is not located in the seismically active area, and there have been no recorded landslide activities in the past few decades. However, there are threats of anthropogenic pressure, as there is evidence of vandalism on site. The suggested carrying capacity is based on the observations performed during the group visits on the site, in the period from April to May 2024. The group counted up to 35 people, and based on the authors' opinion, a large number of visitors on the site at the moment would possibly cause the reduction of visual quality and conformity of the visitors.

The ecological values of Sokograd are also noteworthy, situated within the natural protected area of Outstanding Natural Landscape "Lepterija – Sokograd," with many specific and rare species, and important ecosystems [74].

4.2.2 TVs

The evaluation of the TVs of the Sokograd fortress can provide insights into its potential for geotourism. Despite receiving somewhat lower scores compared to UGV, the well-preserved parts of the site, such as the tower, entrance, water reservoir, and defensive walls, offer excellent educational opportunities. There is a possibility to interpret information about geology, particularly regarding the genesis and characteristics of the building stones.

The visible construction materials of Sokograd present opportunities for educating tourists about various aspects of geology, including rock types, lithology, hardness, colour, processing methods, and their local origins. This niche segment of tourism recently gained big popularity worldwide [4,5,10,35,75–81], as this information is relatively easy for most tourists to understand. Currently, promotional activities for the site are limited to the regional level, primarily conducted by the Tourism Organization of Sokobanja. Using modern technologies and promotional activities (internet, social networks, event organization, etc.) will help this site to be promoted on a national or even international level [82–86]. Information boards, a common and cost-effective form of interpretation and promotion [87], are lacking in quality on the site, receiving a low rating. To enhance tourism development, attention should be given to increasing the number of information boards, their strategic positioning, and improving the quality and content of their illustrations, as high-quality interpretive panels hold significant importance for self-guided tours [63]. Guided tours are one of the popular methods of geoheritage interpretation that does not require significant investments. Efficient verbal interpretation is crucial for enhancing the tourist experience. High-quality and multilingual guide services are necessary to explain complex geological and geomorphological processes, as geotourists are typically looking for knowledge about these subjects. Tour guides should enhance visitors' awareness of the importance of geoheritage and its conservation [88]. Investing in the education of tour guides about geology and geomorphology would undoubtedly lead to a more enriching tourist experience.

The information centre, located a few kilometres from the site, offers limited services to visitors, primarily providing promotional materials, souvenirs, and basic information about the history of the area. Visitor centres are an important part of the tourism destination and interpretation worldwide where tourists can communicate with the destination and participate in various educational programmes [89,90]. The existing tourism infrastructure on and near the site is of lower quality, posing a challenge for improvement, including parking areas, footpaths, rest areas, toilets, and waste disposal facilities.

Accessibility to the Sokograd fortress, situated on a high limestone ridge on the edge of the urban area, is only possible on foot, presenting safety concerns such as the risk of debris falls and slippery rocks, especially during adverse weather conditions. Installing handrails and fences would enhance the safety and encourage greater tourist activation of the site. Safety measures are effectively implemented in the geocultural site Golubac fortress, and there are zones for full access and limited access.

Effective tourism development relies on the cooperation between the local community and tourism stakeholders. Community involvement is crucial for exchanging ideas and establishing strong connections between locals, protected areas, and officials. This connection not only enhances the understanding of tourism practices among locals but also drives economic growth in the community. An illustrative instance is the Luochuan Loess National Geopark in China, where the local community received training and education to participate in tourism activities within the geopark area [91].

4.2.3 UGAM matrix

The conclusive results of the evaluation process, as presented in Table 6 and Figure 7, affirm Sokograd's potential for urban geotourism, particularly highlighting its natural and protection values. The evaluated geosite is situated in field U_{33}, which means that it has medium values for both UGV and TV. Comparing the results of Sokograd fortress (UGV = 137.47; TV = 129.08) with the UGAM analysis of the geocultural site Felix Romuliana [35] (UGV = 145.78; TV = 171.78), it can be concluded that both sites are located in the field U_{33}, but there are differences in some indicator values. The Sokograd fortress has slightly higher scientific values (especially values of paleo significance and ecological values), but the Felix Romuliana has slightly higher natural values (surface and aesthetic values) and protection values (protection level and carrying capacity). The Felix Romuliana also has significantly higher TVs, as this site is a well-known tourist attraction with developed tourism infrastructure, tour guide service, promotional activities, and information panels. Aligning with contemporary geotourism trends (educational guided tours, information boards with AR or QR codes for self-guided tours, and audio guides), modernizing its infrastructure and promotion will propel Sokograd towards becoming a recognizable urban geotourism destination in the region. With the enhancement of these elements, Sokograd's position in the UGAM matrix could elevate to U_{34} or beyond.

4.3 Degradation risk analysis

The results gathered regarding the degradation risk of the geocultural site Sokograd, near Sokobanja, are outlined in Table 7. The obtained results could be useful for the future managerial plan for tourism development at the site. The findings indicate that certain geosite has a low level of susceptibility and exposure to threats (both human and natural). The Sokograd obtained a score lower than 200, which means that it is of low degradation risk. However, it is necessary to target geoconservation measures to support sustainable tourism development. There are a lot of examples [29–31] where over-tourism caused irreversible damage to the site due to inadequate and ineffective management. As the building stone used at Sokograd and the old Roman aqueduct are significant for Earth Science dissemination, it is important to highlight its educational and scientific value. The site itself is robust, and the building material composition has greater resilience against a variety of threats. Also, the location of the site limits the arrival of a large number of tourists, which can cause deterioration. It is important to mention that good accessibility is significant for tourism development; however, more tourists can cause more pressure on the site leading to higher degradation risk. So, the management of the destination should find the best solution to make this site easily accessible, with low degradation risk. The parking lots should be distant from the site, and a walking path of at least 1 km should lead to the destination. In the case of the Sokograd fortress, this managerial solution is feasible because of terrain physiognomy. It is also important to highlight local community involvement in tourism development; however, more people situated near the site may cause human-induced deterioration. Education of the local community and all other stakeholders about the significance of the site may raise their perception of the site's value, so this could lead to degradation risk mitigation. According to Comer and Willems [30], archaeological sites and landscapes should be presented not as recreational parks but as museums or laboratories. It is essential for visitors to understand the fragile nature of the antiquities and have opportunities to learn and enjoy related experiences outside the sensitive areas. A visit to the site should serve as a foundation for interpretation, which should primarily occur in locations that do not contain delicate resources and where local communities are or will be established. So, the Sokograd fortress possesses values that can serve as an open air museum or laboratory, and the management should take action according to this manner. A big problem at the site is human-induced damage. Vandalism and graffiti on the

Table 7: Total values of degradation risk for the geocultural site Sokograd fortress

Degradation risk criteria	Weight	Urban geosite Sokograd	Total values
A. Deterioration of geological elements	35	2	70
B. Proximity to areas/activities with potential to cause degradation	20	1	20
C. Legal protection	20	2	40
D. Accessibility	15	1	15
E. Density of population	10	1	10
Total	100		155

site send a bad image to the public. Wilson and Kelling [92] presented the “broken window theory” referring that the visual environment provides cues that establish norms, influencing people to behave in ways that appear normal and acceptable based on their surroundings. So, the first step in the further development of tourism in the Sokograd fortress is to prevent those actions by constant monitoring of the site and establishing regulations. They [92] also referred to intrusive development, as it sends a message to all stakeholders that if intrusive development is present, other intrusive actions are also acceptable. So, future managerial plans should prevent intrusive development of tourism on the site (e.g. accommodation facilities and restaurants), as Sokograd is located in the heart of nature protected area “Lepterija-Sokograd,” and main ecological values should be preserved.

5 Conclusions

This article aimed to present the geoheritage values of the geocultural site Sokograd fortress. The UGAM for assessing the tourism potential of urban geosites provided insight into the advantages, disadvantages, limitations, and potentials of urban geotourism development at the Sokograd fortress. The UGAM parameters revealed that the Sokograd fortress has highly rated values related to geoheritage diversity and geocultural and ecological values significant for the dissemination of Earth Science. On the other hand, low values of tourism infrastructure, guide service, and information boards limit the tourism possibilities of this site. The results of degradation risk assessment provided the conclusion that further tourism development would not cause serious damage to the site, but it has to be performed with high responsibility in a sustainable way. A mineralogical–petrographical study of selected building stones at the Sokograd fortress confirmed that this site has a significant petrographical diversity of sedimentary rock types (limestone, sandstone, tufa, and conglomerates) of local provenance, which is a great opportunity for educational activities and Earth Science dissemination. As urban geotourism falls under specific types of tourism, utilizing this site for educational purposes, such as organizing field trips or workshops for students and teachers, would affect its popularity and put it on the geotouristic map of Serbia. Urban geotourism of Sokograd cannot be a significant motive for the visitors of Sokobanja, as there are many natural resources that attract a large number of visitors during the year, but it could be a complement to the existing tourism offer (ecotourism, rural tourism, and health tourism), and it could fill a gap of the geotourism offer in the future.

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