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Damage Assessment of Building Materials and Conservation Recommendations for Karacabey Ulu Mosque in Bursa

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Abstract
Karacabey Ulu Mosque is an example of an Ottoman transitional period mosque minaret and has been exposed to numerous disasters over the years. The structure suffered severe damage during earthquakes and the Karacabey Fire in the years of the Turkish War of Independence, and after each restoration, it lost some of its original architectural characteristics. Today, various deterioration problems are still present, and the conservation and sustainability of the building have become an urgent necessity. The aim of this study is to identify stone material deterioration patterns and their causative factors in Karacabey Ulu Mosque in Bursa, in order to provide scientific monitoring and decision support for future restoration works. For this purpose, the material deteriorations observed in the structure were classified based on the deterioration types defined in the ICOMOS-ISCS, and tabulated accordingly. The deteriorations identified through on-site observations were marked on these tables. In this method, the data obtained through visual inspection were documented with photographs and evaluated. As a result of the study, it was concluded that the sources of water and moisture within the structure, as well as the potential seismic effects on the building, should be urgently investigated in detail.
Keywords: Damage, Material Problems, ICOMOS-ISCS, Restoration, Conservation.

1. INTRODUCTION

It was stated by the experts at the First International Congress of Architects and Technicians of Historic Monuments, held in Athens in 1931, that stone monuments across the world are increasingly threatened by atmospheric agents (ICOMOS, 1996). From this early observation to the present day, a review of the literature on material deterioration in monuments reveals that this problem has progressively intensified over the years due to various climatic and anthropogenic factors. It is widely emphasized that, unless urgent preventive measures are taken, a significant portion of the world's stone cultural heritage, comprising structures such as castles, temples, churches, and palaces, will gradually deteriorate and ultimately disappear (Fitzner, 2002; Cutler et al., 2013; Adamopoulos and Rinaudo, 2021; Hatır et al., 2021; Patil et al., 2021; Kramar et al., 2011; Bozdağ et al., 2019; Delgado Rodrigues, 2015; Siegesmund and Snethlage, 2011; Alaimo et al., 1997; Korkanç, 2013; Topal and Sözmen, 2003; De Gennaro et al., 2001; Küçükkaya, 2004; Zarif and Gürpınar, 2012; Uchida et al., 1999; Lee and Yi, 2007; Lee et al., 2005; Heinrichs, 2008; Salonia and Negri, 2003; Scolastico, 2006; ICOMOS-ISCS, 2008; Lisci et al., 2003; Marszalek, 2004; Silva et al., 2010; Evans, 1970; Cassar, 2002; Sanjurjo-Sánchez and Alves, 2012). In order to prevent this threat, a common emphasis across these studies is that the initial assessment of a historic building should begin with a visual inspection. This should be followed by a comprehensive analysis and photographic documentation of deterioration patterns, and ultimately, the structure should be thoroughly documented in a systematic manner.

Based on the recommendations emphasized in the literature, Bursa Karacabey Ulu Mosque, an architectural structure that has undergone multiple restorations yet still exhibits significant damage, was selected as the subject of this study. The building holds considerable historical value for the region. It has suffered severe damage due to earthquake events and the Karacabey Fire during the years of the Turkish War of

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Independence, followed by several restoration interventions. However, after each restoration, the structure has lost certain aspects of its original architectural character. Today, various forms of deterioration are still evident, making the conservation and sustainable preservation of the building an urgent necessity.

Within this context, the aim of the study is to identify material damage patterns and deterioration factors in order to provide scientific monitoring and decision-support tools for experts during the restoration process. The material deteriorations identified through fieldwork and observational analysis were systematized in tabular form, and the resulting data were interpreted accordingly.

1.1. Case Study: Bursa Karacabey Ulu Mosque

1.1.1. Location

It is known that the settlement in the region dates back to the Mysians, who migrated to the area in the 12th century BCE, and that a city named Miletepolis existed within the present-day boundaries of Karacabey during that period. One of the most significant monuments of the Karacabey region is the Ulu Mosque commissioned by Sultan Murad I. Bursa Karacabey Ulu Mosque is located in the Garipçe Neighborhood of the Karacabey district of Bursa (Karacabey Municipality, 2014) (Figure 1).

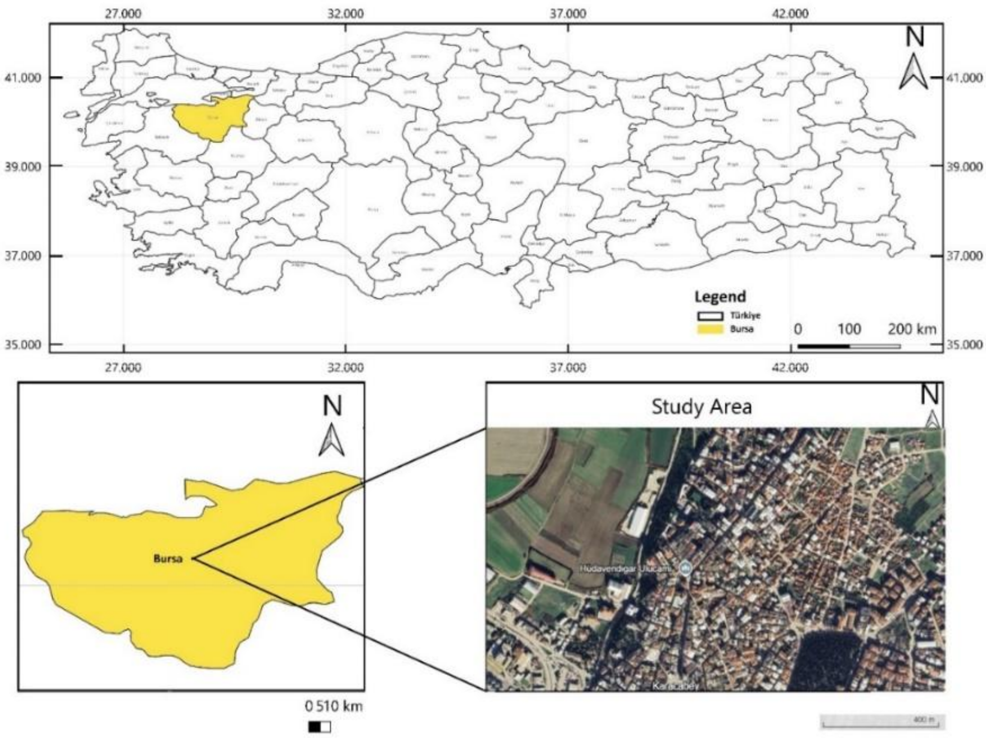

Figure 1. Location of Karacabey Ulu Mosque (adapted from Google Earth).

1.1.2. Historical background of the structure and ıts restoration ınterventions

Karacabey Ulu Mosque was commissioned by Sultan Murad I and is therefore also locally known as the "Hüdavendigar Ulu Mosque." Due to the absence of an inscription, the exact construction date of the building remains unknown. Archival records indicate that the mosque has a layered history shaped by fires and successive restoration interventions. Throughout its historical process, the structure has experienced two major fires and has undergone four restoration phases. The first intervention is thought to have taken place between 1475 and 1476. During the reign of Sultan Abdülhamid II, a second storey was added to the structure, and modifications were made to the façade elements. During the Greek occupation between 1919 and 1922, the mosque suffered another fire; however, the extent of the damage remains unclear. In the Republican period, as conservation practices became institutionalized, efforts were made to restore the building to its original state. In this context, the minaret was reconstructed in 1962, followed by a comprehensive restoration carried out by the General Directorate of Foundations in 1964. The most recent major intervention took place in 2012. During this process, a fire that broke out during restoration led to the complete renewal of the wooden elements and the ceiling structure. Additionally, concrete and cement coatings that were incompatible with the original fabric were removed, some later additions were eliminated, and spatial reconfigurations were implemented (Kaplan, 2025) (Table 1). All these interventions demonstrate that Karacabey Ulu Mosque is a continuously transforming structure bearing traces of different historical periods, thus representing a multi-layered cultural heritage asset extending from the Ottoman era to the present.

Table 1. Intervention Analysis of Karacabey Ulu Mosque

Period / Date	Type of Intervention	Description of Intervention	Spatial / Structural Impact	Material / Conservation Impact
14th century (Reign of Murad I, 1362–1389)	Construction	The mosque was constructed (commissioned by Murad I Hüdavendigar; no inscription, exact date unknown)	Original plan and spatial configuration were established	Original materials and construction techniques (e.g., alternating stone–brick masonry) were used
1475–1476 (estimated)	Repair	First known repair intervention	Continuity of use of the existing structure was ensured	Early intervention; assumed to be compatible with original materials
Reign of Abdülhamid I (1774–1789)	Repair / Adaptive reuse	Repair dated 1118 AH (1774 AD); architectural evidence indicates a significant intervention during this period	Partial changes in spatial organization	Additions and modifications in façade and interior arrangements
1919–1922	Disaster (Fire)	The mosque was burned during the Karacabey fire in the Greek occupation period	Certain parts of the structure (especially wooden elements) were severely damaged	Material loss, structural deterioration, and fire-related damage occurred
1962	Reconstruction	The collapsed minaret was rebuilt (by local craftsman Salim Usta)	Vertical emphasis and silhouette (minaret) were reintroduced	Partial reconstruction with new materials; contribution to original silhouette
1964	Restoration	Comprehensive repair and restoration by the General Directorate of Foundations	Overall structural and spatial continuity of the building was ensured	Conservation-oriented intervention; damaged parts repaired and the mosque reopened for worship
2012 (March)	Restoration + Disaster (Fire)	A major fire broke out during restoration works (during plaster removal)	Interior space, wooden roof, and upper structure were heavily damaged	Significant loss of wooden elements; the mosque was almost entirely burned, leaving mainly the stone walls
2012 (post-fire)	Cleaning / Removal	Concrete, plaster, cement coatings, and incompatible later additions were removed	Original surface perception and masonry became visible again	Efforts to enhance material authenticity; incompatible modern layers were removed
2012	Removal / Simplification	Metal eaves, canopies, and some incompatible additions were removed	Façade and entrance space were simplified	Later incompatible materials were eliminated
2012	Reorganization	Ablution areas were removed and a new fountain (şadırvan) was constructed	Functional layout was reorganized	Introduction of a contemporary addition (fountain)
2012	Spatial Transformation	Imam's room was relocated and the windbreak entrance was removed	Interior circulation and usage patterns changed	Interventions on interior spatial elements
2012 (post-fire)	Reconstruction / Restoration	Wooden elements, roof, and other parts damaged by fire were rebuilt	Interior character was partially re-established	Although posing a risk to authenticity, functional continuity was ensured

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Source: The Table 1, compiled by the author based on data obtained from various studies on the structure (Kaplan, 2025; Ötüken et al., 1986; Republic of Türkiye Ministry of Culture and Tourism; Karacabey Municipality, 2014).

1.1.3. Architectural and structural characteristics

The main prayer hall of Karacabey Ulu Mosque extends along the north–south axis. The structure measures 9.28 × 11.28 m and is designed as a regular rectangular mass. A narthex (last congregation area) measuring 2.34 × 9.26 m is attached to the northern façade. The minaret is located on the eastern façade, adjoining the wall that separates the prayer hall from the narthex. It rises on a polygonal base and has a hexadecagonal (sixteen-sided) shaft. In terms of construction technique, the mosque features an alternating masonry system (stone–brick bonding), which is commonly observed in early Ottoman architecture. The load-bearing walls and the base of the minaret are constructed using a combination of rubble stone and brick. In addition, an inscribed stone located at the southeastern corner indicates the use of spolia during the construction process.

The interior is characterized by a simple design. The most prominent decorative element is the mihrab, which is entirely made of marble. Apart from this, the only element where inscription is used as a decorative feature is the construction inscription panel. This inscription is carved onto a marble surface within a rectangular frame divided into panels.Structurally, the building largely relies on its load-bearing walls. The thickness of the main walls surrounding the prayer hall is approximately 1.00 m, while the northern, eastern, and western walls enclosing the narthex are about 0.75 m thick. In terms of height, the main walls reach approximately 8.52 m, whereas the walls of the narthex are about 4.56 m high. The wide span of the interior is covered by a wooden ceiling and roof system, which is supported by twelve wooden columns positioned within the space to balance the load. These columns rise from the floor to the women's gallery (mahfil) and continue upward toward the ceiling. At the gallery level and at the junction points with the ceiling, the system is reinforced with traditional wooden brackets (eliböğründe), enhancing the structural stability of the building (Kaplan, 2025) (Figure 1).

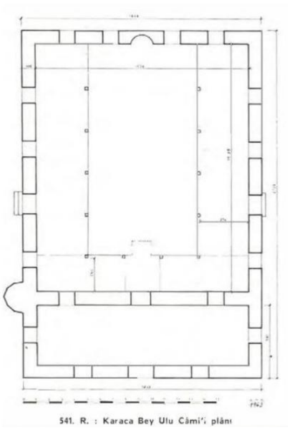

Figure 2. Plan of Karacabey Ulu Mosque (Ayverdi, 1989).

2. METHOD

In this study, the visual inspection method was employed to identify and classify the material deteriorations observed in the structure. Different parts of the building, including walls, floors, roofs, stairs, and auxiliary elements (such as decorative features, moldings, eaves, chimneys, and window pediments), were examined in detail on site. The types of deterioration identified during the field survey were classified according to the categories defined in the ICOMOS-ISCS (2008) Illustrated Glossary on Stone Deterioration Patterns. The deterioration types defined in this standard were tabulated based on building elements (walls, floors, roofs, stairs, and auxiliary elements), and the observed deteriorations were marked within the table. This approach enabled a clear identification of which types of deterioration were present in each building component.

Each type of deterioration was documented photographically, and notes were taken regarding its intensity, distribution, and location within the structure. The study adopted a non-destructive, non-invasive approach; no laboratory analyses were conducted, and only in-situ visual assessment and mapping methods were applied. The collected data were summarized in both tabular and textual forms, allowing the most common types of deterioration in the building to be identified.

3. FINDINGS

3.1. Mapping the observed deterioration onto the prepared damage table

In the initial stage, the monument was examined on site and photographic documentation was carried out. The deterioration types identified through in-situ observations were named based on the terminology provided in the glossary published by ICOMOS (ICOMOS-ISCS, 2008). These deterioration types were then recorded on a chart prepared to identify material deterioration at the level of building elements.

The chart developed within the scope of this study is intended for the identification and documentation of stone material deterioration across different building components. The main types of deterioration observed in the structure are presented in detail in the table below (Table 2).

Table 2. Types of stone material deterioration observed in the structure

Stone Material Damage Type	Damage Type	walls	floors	roof	stairs	auxiliary elements
CRACK & DEFORMATION	CRACK	X	X	X		X
	DEFORMATION					
DETACHMENT	BLISTERING	X				
	BURSTING					
	DELAMINATION					
	DISINTEGRATION	X				
	FRAGMENTATION					
FEATURES INDUCED BY MATERIAL LOSS	PEELING	X				X
	SCALING	X				
	ALVEOLIZATION					
	EROSION	X	X	X		X
	MECHANICAL DAMAGE		X			
	MICROKARST					
	MISSING PART	X	X			
	PERFORATION					
	PITTING					
DISCOLOURATION & DEPOSIT	CRUST	X		X		X
	DEPOSIT	X		X		X
	DISCOLOURATION	X	X	X		X
	EFFLORESCENCE	X				
	ENCRUSTATION					
	FILM					
	GLOSSY ASPECT					
	GRAFFITI					
	PATINA	X				
BIOLOGICAL COLONIZATION	SOILING	X	X			X
	SUBFLORESCENCE					
	BIOLOGICAL COLONIZATION	X	X	X		X

	ALGA	**X**	**X**	**X**		**X**
	LICHEN					
	MOSS	**X**	**X**	**X**		**X**
	MOULD					
	PLANT					

Source: The Table 2 was developed based on the classification of material deterioration adapted from ICOMOS-ISCS, 2008, and organized according to building elements.

The deterioration types presented in the table are explained in detail in the following sections, based on the visual data obtained from the field.

3.2. Evaluation of the Damage Table Through Photographs

3.2.1. *Material deterioration observed on walls*

The most common deterioration observed on the walls includes intense discolouration visible across nearly all surfaces, along with dirt accumulation and surface soiling (soiling and deposit). Biological colonization is also widespread, particularly in lower and humid areas, in the form of moss and algae growth (Figure 3).

Figure 3. Material deterioration observed on walls *(Özçelik, Z. S., 2026)*

Significant erosion and material loss are evident on stone surfaces, while cracks are commonly observed in both stone and brick elements. Material detachment is present in the form of blistering, peeling, and scaling. In certain areas, structural disintegration of stones is observed, along with localized loss of small stone parts (missing parts). Some stones exhibit patina formation, and slight efflorescence is visible near the eaves. Additionally, crust formation is observed in the white plastered areas. No deterioration was identified in the wooden columns visible in the interior, as they have undergone restoration (Figure 4).

Figure 4. Material deterioration observed on walls *(Özçelik, Z. S., 2026)*

3.2.2. Material deterioration observed on floors

The most prominent issues observed on the floors include intensive erosion caused by human use and environmental factors, as well as mechanical damage. Particularly along circulation paths and entrance areas, significant wear and polishing of stone surfaces are evident. In some areas, cracks have developed, along with moisture-related discolouration and surface soiling. Biological colonization in the form of moss and algae layers has also been identified in certain areas, and small fragments have detached from stone edges (detachment and missing part) (Figure 5).

Figure 5. Material deterioration observed on floors *(Özçelik, Z. S., 2026)*

3.2.3. Material deterioration observed on roofs

On the roofs, the most significant issue is the excessive moisture retention, particularly in the eaves and gutter system. Due to continuous moisture exposure and water infiltration, discolouration, as well as the accumulation of dirt and deposits, has been observed. Crust formation is evident in the areas beneath the eaves, while material detachment and erosion have developed over time. Additionally, cracks have formed at the junction points of stone elements, and biological colonization in the form of moss and algae has been identified.

3.2.4. Material Deterioration Observed on Stairs

No deterioration was identified on the stairs visible in the interior, as they have undergone restoration.

3.2.5. Material Deterioration Observed on Auxiliary Elements

In auxiliary elements such as decorative features, mouldings, arches, chimneys, window pediments, and eaves, several types of deterioration have been identified. Chimneys, eaves, and window mouldings exhibit intense discolouration, along with significant dirt accumulation (soiling and deposit), particularly in chimney and eaves areas. Erosion leading to surface loss is observed on chimney stones. In lower and humid areas, widespread biological colonization in the form of moss and algae is present. Cracks have developed on mouldings and around window elements, while material detachment in the form of peeling is observed on window mouldings. Additionally, crust formation is evident in the areas beneath the eaves (Figure 5).

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Figure 6. Material deterioration observed on auxiliary elements *(Özçelik, Z. S., 2026)*

4. DISCUSSION

The aim of this study is to identify stone material deterioration patterns of the monumental structure of Bursa Karacabey Ulu Mosque in order to provide scientific monitoring and decision support for experts during the restoration process. For this purpose, the material deteriorations observed in the structure were classified according to building elements (walls, floors, roofs, stairs, and auxiliary elements), based on the deterioration types defined in the ICOMOS-ISCS (2008) *Illustrated Glossary on Stone Deterioration Patterns*. The observed deteriorations were then mapped onto the prepared table. Within this method, the data obtained through visual inspection were documented and evaluated using photographic records. The predominant deterioration types identified in the structure include moisture-induced biological colonization, erosion, cracking, and discolouration caused by surface contamination.

Biological colonization, particularly in the form of moss and algae, is one of the most prominent deterioration problems observed in the structure and generally occurs due to moisture and humidity. High humidity levels and water accumulation around the building create a suitable environment for the growth of moss. The layer of moss and algae formed on moist surfaces can increase the porosity of the stone, leading to its weakening. In historic stone structures, the lack of regular cleaning and maintenance can further promote vegetation growth. Moss, lichens, and other plant species may settle on surfaces over time, causing gradual deterioration of the stone. If not properly cleaned, plant roots can damage the stone surface. Intensive biological colonization in stone structures is also closely related to the porosity of the material. Stones with high porosity absorb water and nutrients, providing a suitable substrate for the growth of such organisms. This process weakens the structural integrity of the stone over time and may result in long-term damage (Gaylarde, 2020). In this context, appropriate measures should be taken to prevent water-related deterioration in the structure.

The findings of the study indicate that one of the most prevalent types of damage observed in the structure is cracking in the walls. In stone buildings, cracks may develop due to various factors. One of the most common causes of cracking in historic stone structures is natural weather conditions. In particular, extreme temperature variations, humidity, and precipitation can lead to the expansion and contraction of stone materials. This cyclic movement may create stress within the walls, resulting in the formation of cracks.

Foundation movements and ground-related problems constitute another significant cause of cracking in historic stone structures. Changes in the soil can disrupt the structural balance of the building and lead to cracking in the walls. Especially soil displacement or compaction may affect the structure and cause cracks. Over time, historic stone buildings may also develop structural deficiencies. This is often associated with repairs or alterations that are not compatible with the original construction techniques. The use of inappropriate materials or improper intervention methods can contribute to crack formation in walls (Ay et al., 2025).

Another major factor that may lead to cracking in the walls of historic stone structures is earthquakes. During seismic events, vibrations and ground movements can cause displacement of stones and the formation of cracks in the walls (Çağlar et al., 2023). Historic stone structures are generally less ductile than modern buildings, meaning that their capacity to absorb energy and deform under stress is limited. As a result, they are more vulnerable to earthquake-induced damage. Seismic vibrations can weaken both the foundation and the wall system of stone structures, leading to cracks and separations at the points where stones are connected (Karataş & Bayhan, 2023; Wigger & Rostasy, 1999).

The Karacabey region and the monumental structure of Karacabey Ulu Mosque have suffered severe damage from past earthquakes. According to the *Turkey Earthquake Hazard Map* published by the Disaster and Emergency Management Authority (AFAD), Karacabey (Bursa) is located in a first-degree seismic zone and is therefore exposed to a high earthquake risk (Disaster and Emergency Management Authority, 2019). The district is situated close to active fault lines, including the Karacabey Fault, which extends approximately 29 km between the Marmara Sea and Karacabey, and the Uluabat Fault. Due to this proximity, the area was directly affected by the Manyas–Karacabey earthquake of 6 October 1964 with a magnitude of Mw 6.8 (Wikipedia, 2024), and it continues to experience frequent low-magnitude tremors today. Furthermore, due to its alluvial soil structure, certain neighbourhoods are at high risk of soil liquefaction. The structural vulnerabilities identified in the building, such as moisture-induced cracks, erosion, and material loss, may further increase the risk during an earthquake. In this context, the findings of this study highlight the necessity of investigating the seismic behavior of the structure and implementing appropriate preventive measures to minimize potential earthquake damage.

5. CONCLUSION

Within the scope of this study, observational data obtained through on-site visual inspection were analyzed and synthesized using a two-dimensional tabulation technique prepared in accordance with the ICOMOS-ISCS (2008) standard. As a result, the stone material deterioration patterns of the monumental structure of Bursa Karacabey Ulu Mosque were identified. The most common types of deterioration observed in the structure are moisture-induced biological colonization, erosion, cracking, and discolouration caused by surface contamination. These damages are considered to be largely associated with earthquake effects and, in particular, insufficient maintenance related to water and moisture exposure.

For the cracks exposed after surface cleaning (raspa) on the walls, epoxy resin injection is recommended. For cracks too wide for injection, a portion of the brick or stone material along the crack should be carefully removed and repaired using compatible materials and stitching techniques. It is essential to investigate whether the observed cracks are caused by earthquakes or other structural factors. In future studies on the stone structure, it would be more appropriate to first examine seismic effects and then develop restoration proposals for the cracks accordingly. Cracking problems in historic stone structures may arise from multiple causes, including natural weather conditions, foundation movements, soil problems, deficiencies in the load-bearing system, structural inadequacies, and earthquakes. In addition, cracks in stone and the processes leading to their formation are influenced not only by climatic and anthropogenic external factors but also by intrinsic material properties such as texture, mineralogy, porosity, and pore size distribution. In this context, future studies should adopt an integrated approach that combines experimental analysis of existing materials with investigations of seismic effects in order to inform the design of appropriate restoration materials. Failure to accurately identify the causes of cracking and the implementation of inappropriate interventions may lead to irreversible consequences.

Within the scope of this study, in order to achieve a deeper understanding of the identified deterioration and to develop sustainable conservation strategies, future research should prioritize the following aspects: detailed laboratory analyses of the mineralogical, petrographic, and porosity characteristics of the stone materials; determination of whether existing cracks are caused by earthquake-induced structural damage or by factors such as moisture, ground movement, and material fatigue through seismic and structural analyses; experimental studies aimed at preventing moisture- and salt-induced deterioration through hydrophobic protective applications and the improvement of drainage systems; and the establishment of regular maintenance and monitoring protocols.

In addition, considering the high seismic risk of the region where Karacabey Ulu Mosque is located, it is recommended that the seismic performance of the structure be modeled using the finite element method and that earthquake-resistant strengthening strategies be developed. Such integrated and multidisciplinary approaches will help prevent inappropriate interventions and ensure the long-term conservation of the structure.

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Conflict of Interest (COI)
There is no conflict of interest.

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