



Postgraduate Dissertation

“Integrated Assessment of Climate-Induced Risks and
Preservation Strategies for the Temple of Apollo at Ancient
Corinth.”





School of Applied Arts and Sustainable Design

M.Sc. Protection of Cultural Heritage and Monuments
of Nature from the Effects of Climate Change

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Postgraduate Dissertation

“Integrated Assessment of Climate-Induced Risks and Preservation
Strategies for the Temple of Apollo at Ancient Corinth.”

Maria Festa

Supervisor: Dr. Zoi Sakki

Athens, Greece, June 2026

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**“Integrated Assessment of Climate-Induced Risks and Preservation
Strategies for the Temple of Apollo at Ancient Corinth.”**

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Athens, Greece, June 2026

*“To my mother, **Foteini**, who fought her own battle with pancreatic cancer with courage and dignity.*

Every step I take is dedicated to her— my greatest source of inspiration.

Her strength will always guide me.

Always in my heart.”

Abstract

Climate change is increasingly recognized as one of the major challenges for the preservation of cultural heritage. Archaeological monuments are particularly vulnerable, as they are continuously exposed to environmental conditions that can accelerate material deterioration and affect their structural stability. Among these monuments, the Temple of Apollo at Ancient Corinth represents a significant example of Archaic Greek architecture and an important component of Greece's cultural heritage.

This dissertation investigates the risks posed by climate change to the Temple of Apollo and examines how environmental and geological factors may influence its long-term preservation. The study aims to assess the monument's vulnerability to climate-related hazards, seismic activity, and other environmental stressors, while evaluating the deterioration processes affecting its materials and structural remains.

To achieve this objective, archaeological, architectural, geological, environmental, and climatic data were integrated within a qualitative and semi-quantitative risk assessment framework. Particular attention was given to the effects of extreme heat, aridity, humidity variability, precipitation, atmospheric pollution, and seismic activity. Future climate conditions were examined through the Representative Concentration Pathways (RCP 4.5 and RCP 8.5) in order to evaluate how projected environmental changes may affect the monument over time.

The results indicate that seismic activity and extreme heat constitute the most significant threats to the Temple of Apollo, while increasing aridity, humidity fluctuations, and atmospheric pollution contribute to the gradual deterioration of its oolitic limestone and structural components. The study also demonstrates that these hazards should not be considered independently, as their interaction can amplify deterioration processes and increase overall vulnerability. Under future climate scenarios, several existing risks are expected to intensify, emphasizing the need for proactive conservation and adaptation measures.

Based on these findings, the dissertation proposes a series of conservation, monitoring, and management strategies aimed at strengthening the monument's resilience to future environmental change. The study highlights the importance of integrating climate-risk assessment into heritage conservation and contributes to the development of

sustainable approaches for the protection of archaeological monuments in the Mediterranean region.

Keywords

Climate Change; Cultural Heritage; Temple of Apollo; Ancient Corinth; Risk Assessment; Conservation Strategies; RCP 4.5; RCP 8.5.

“Ολοκληρωμένη Αξιολόγηση Κλιματικών Κινδύνων και Στρατηγικών Διατήρησης για τον Ναό του Απόλλωνα στην Αρχαία Κόρινθο.”

Μαρία Φέστα

Περίληψη

Η κλιματική αλλαγή αναγνωρίζεται πλέον ως μία από τις σημαντικότερες προκλήσεις για τη διατήρηση της πολιτιστικής κληρονομιάς. Τα αρχαιολογικά μνημεία είναι ιδιαίτερα ευάλωτα, καθώς εκτίθενται διαρκώς σε περιβαλλοντικούς παράγοντες που μπορούν να επιταχύνουν τις διαδικασίες φθοράς και να επηρεάσουν τη δομική τους σταθερότητα. Ο Ναός του Απόλλωνα στην Αρχαία Κόρινθο αποτελεί ένα από τα σημαντικότερα σωζόμενα μνημεία της Αρχαϊκής περιόδου στην Ελλάδα και ένα εμβληματικό στοιχείο της ελληνικής πολιτιστικής κληρονομιάς.

Η παρούσα διπλωματική εργασία διερευνά τους κινδύνους που προκύπτουν από την κλιματική αλλαγή για τον Ναό του Απόλλωνα και εξετάζει τον τρόπο με τον οποίο περιβαλλοντικοί και γεωλογικοί παράγοντες επηρεάζουν τη μακροχρόνια διατήρησή του. Στόχος της έρευνας είναι η αξιολόγηση της ευπάθειας του μνημείου απέναντι σε κλιματικούς κινδύνους, σεισμική δραστηριότητα και άλλες περιβαλλοντικές πιέσεις, καθώς και η διερεύνηση των μηχανισμών φθοράς που επηρεάζουν τα δομικά υλικά και τα σωζόμενα αρχιτεκτονικά του στοιχεία.

Για την επίτευξη του στόχου αυτού συνδυάστηκαν αρχαιολογικά, αρχιτεκτονικά, γεωλογικά, περιβαλλοντικά και κλιματικά δεδομένα στο πλαίσιο μιας ποιοτικής και ημι-ποσοτικής μεθοδολογίας εκτίμησης κινδύνου. Ιδιαίτερη έμφαση δόθηκε στις επιπτώσεις της ακραίας θερμότητας, της αυξανόμενης ξηρασίας, των μεταβολών της υγρασίας, των κατακρημνίσεων, της ατμοσφαιρικής ρύπανσης και της σεισμικής δραστηριότητας. Παράλληλα, εξετάστηκαν μελλοντικές κλιματικές συνθήκες μέσω των σεναρίων αντιπροσωπευτικών διαδρομών συγκέντρωσης αερίων του θερμοκηπίου (RCP 4.5 και RCP 8.5), προκειμένου να αξιολογηθούν οι πιθανές επιπτώσεις των προβλεπόμενων περιβαλλοντικών μεταβολών στο μνημείο.

Τα αποτελέσματα έδειξαν ότι η σεισμική δραστηριότητα και τα φαινόμενα ακραίας θερμότητας αποτελούν τους σημαντικότερους παράγοντες κινδύνου για τον Ναό του Απόλλωνα, ενώ η αυξανόμενη ξηρασία, οι διακυμάνσεις της υγρασίας και η ατμοσφαιρική ρύπανση συμβάλλουν στη σταδιακή υποβάθμιση του ωολιθικού ασβεστόλιθου και των δομικών στοιχείων του μνημείου. Η έρευνα ανέδειξε επίσης ότι οι κίνδυνοι αυτοί δεν δρουν μεμονωμένα, αλλά αλληλεπιδρούν μεταξύ τους, ενισχύοντας τις διαδικασίες φθοράς και αυξάνοντας τη συνολική ευπάθεια του μνημείου. Υπό τα εξεταζόμενα κλιματικά σενάρια, αρκετοί από τους υφιστάμενους κινδύνους αναμένεται να ενταθούν στο μέλλον, γεγονός που καθιστά αναγκαία την εφαρμογή προληπτικών μέτρων προστασίας και προσαρμογής.

Με βάση τα ευρήματα της μελέτης προτείνονται μέτρα διατήρησης, παρακολούθησης και διαχείρισης που αποσκοπούν στην ενίσχυση της ανθεκτικότητας του μνημείου απέναντι στις μελλοντικές περιβαλλοντικές μεταβολές. Η εργασία αναδεικνύει τη σημασία της ενσωμάτωσης της εκτίμησης κλιματικού κινδύνου στη διαχείριση της πολιτιστικής κληρονομιάς και συμβάλλει στην ανάπτυξη βιώσιμων προσεγγίσεων για την προστασία αρχαιολογικών μνημείων στον μεσογειακό χώρο.

Λέξεις – Κλειδιά

Κλιματική Αλλαγή, Πολιτιστική Κληρονομιά, Ναός του Απόλλωνα, Αρχαία Κόρινθος, Εκτίμηση Κινδύνου, Στρατηγικές Διατήρησης, RCP 4.5, RCP 8.5.

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List of Abbreviations & Acronyms

3D – Three-Dimensional

AI – Aridity Index

AQI – Air Quality Index

ASCSA – American School of Classical Studies at Athens

BC – Before Christ

CC – Climate Change

CCTHaz – Combined Climate Threat Hazard

CE – Common Era

CH – Cultural Heritage

DEAR-Clima – Data Extraction Application for Regional Climate

EHHaz – Extreme Heat Hazard

EPHaz – Extreme Precipitation Hazard

FHaz – Frost Hazard

FWI – Fire Weather Index

GHG – Greenhouse Gas

GIS – Geographic Information System

HHI – Heritage Hazard Index

ICOMOS – International Council on Monuments and Sites

IPCC – Intergovernmental Panel on Climate Change

LiDAR – Light Detection and Ranging

NO₂ – Nitrogen Dioxide

NO_x – Nitrogen Oxides

O₃ – Ozone

PET – Potential Evapotranspiration

PGA – Peak Ground Acceleration

PM_{2.5} – Particulate Matter $\leq 2.5 \mu\text{m}$

PM₁₀ – Particulate Matter $\leq 10 \mu\text{m}$

PR₉₉ – Extreme Precipitation Indicator

RCP – Representative Concentration Pathway

RH – Relative Humidity

SHaz – Seismic Hazard

SLR – Sea Level Rise

SO₂ – Sulfur Dioxide

TN – Minimum Temperature

TN₀ – Frost Days Indicator

TX – Maximum Temperature

TX₃₇ – Days with Temperature > 37°C

UNDRR – United Nations Office for Disaster Risk Reduction

UNESCO – United Nations Educational, Scientific and Cultural Organization

UNFCCC – United Nations Framework Convention on Climate Change

WMO – World Meteorological Organization

1 Introduction

The Temple of Apollo at Ancient Corinth is widely regarded as one of the most significant surviving monuments of Archaic architecture in Greece. Constructed in the 6th century BC, the temple exemplifies the religious, political, and economic significance of Corinth as a pivotal nexus within the ancient Mediterranean world. The temple was dedicated to Apollo¹ and it stood as a defining landmark within both the sacred and urban landscapes of the city (Hellenic Ministry of Culture and Sports, n.d.; Burkert, 1985). The identification of the monument was confirmed in the late 19th century through careful excavations by the American School of Classical Studies at Athens (ASCSA), led by Wilhelm Dörpfeld, and found to correspond with the descriptions of Pausanias (Powell, 1905). Beyond its historical and religious significance, the temple also serves as a lasting symbol of Corinth's cultural identity and historical continuity (Bookidis & Stroud, 2004; Kissas et al., 2015).

Despite its partial preservation, the surviving Doric columns, capitals, and foundation structures offer valuable insights into early Greek stone construction techniques, architectural proportions, and the principles that guided Archaic temple design. These remains reveal the technical skill and aesthetic sensibilities of the Corinthian builders, allowing scholars to trace the development and standardization of Doric architecture within the broader context of ancient Greece (Hellenic Ministry of Culture and Sports, n.d.; Andrikou, 2019).

The temple's long-term deterioration has been exacerbated by natural factors, including seismic events and climatic conditions, as well as human activity, such as tourism and urban development. These activities contribute to the deterioration through vibrations, pollution, and accidental contact. The phenomenon of climate change has been demonstrated to exacerbate the rate of decay through a variety of means, including extreme weather events, temperature fluctuations, altered precipitation, and humidity, particularly in regions exhibiting high seismic activity, such as Corinth (IPCC, 2021; Kapsomenakis et al., 2022). Consequently, the preservation of the Temple of Apollo necessitates the implementation of integrated conservation strategies, encompassing

¹ Apollo: Ancient Greek god of light, harmony, divination, and music. According to Burkert (1985), his worship is closely linked to the concept of order, boundaries, and political cohesion in ancient Greek cities.

structural reinforcement, continuous environmental monitoring, and regulated visitor management, to ensure its sustainable protection as a paradigmatic exemplar of Archaic Doric architecture (IPCC, 2023).

Aims & Objectives

This study analyzes the impact of long-term environmental processes and contemporary climate change on the Temple of Apollo at Ancient Corinth, emphasizing the vulnerability of its architectural remains to ongoing and future deterioration. Drawing on archaeological, architectural, and environmental research, the study explores how historical natural factors, such as seismic activity and climatic conditions, have shaped the monument's preservation over time. Additionally, it examines how contemporary stressors, such as temperature fluctuations, altered precipitation patterns, increased humidity, and human pressures like tourism and urban development, exacerbate material decay and structural instability. By situating the Temple of Apollo within the broader context of climate-related risks in the Mediterranean, this research aims to highlight the cumulative effects of environmental and anthropogenic factors on Archaic stone monuments and to underscore the necessity of integrated conservation strategies for their sustainable preservation (IPCC, 2021; Kapsomenakis et al., 2022).

The specific objectives guiding the present study are as follows:

- To evaluate the cultural, architectural, and historical significance of the Temple of Apollo, situating the monument within the broader framework of Archaic Doric architecture and examining its role in the urban, political, and religious landscape of Ancient Corinth.
- To assess the current state of preservation of the Temple of Apollo, focusing on the condition of construction materials, structural stability, and the extent and significance of the surviving architectural elements.
- To identify and analyze the principal environmental and anthropogenic threats affecting the monument, including climate variability, seismic activity, atmospheric pollution, salinity, tourism-related pressures, and their cumulative impact on material decay and structural vulnerability.

- To propose integrated conservation and risk mitigation strategies that emphasize preventive conservation, continuous monitoring, and emergency preparedness for extreme climatic and seismic events, within the broader framework of sustainable heritage management and climate adaptation.

Methodology

This research employs a risk-oriented methodological approach to investigate the effects of both long-term environmental processes and contemporary climate change on the Temple of Apollo at Ancient Corinth. The monument has been selected as a case study due to its architectural significance as one of the earliest preserved Doric temples in mainland Greece, as well as its location within a region characterized by significant seismic activity and pronounced climatic sensitivity in the eastern Mediterranean.

The scope of the study does not extend to the production of detailed engineering designs or the formulation of specific technical intervention proposals. Instead, the emphasis is placed on the development and application of a conceptual and methodological framework suitable for the assessment of climate-related risks affecting archaeological stone monuments. To this end, the research adopts a qualitative and semi-quantitative methodology based on the analytical relationship between hazards, exposure, and vulnerability. The present approach combines climate and environmental data derived from the scientific literature with site-specific structural and environmental information, as well as the use of standardized risk assessment tools, with the objective of identifying vulnerable components and assessing their relative risk levels.

Within this methodological framework, the study is structured around the following research questions:

- In what ways have seismic activity and climatic conditions historically influenced the preservation and transformation of the Temple of Apollo?
- Which architectural elements and construction materials exhibit the highest vulnerability to current and projected climate-related stressors?

- How do compound risk factors, including climate variability, seismic hazard, and human-induced pressures, interact to accelerate the monument's deterioration?
- Which preventive and adaptive conservation approaches are most suitable for strengthening the long-term resilience of the Temple of Apollo within a sustainable heritage management framework?

2 The Temple of Apollo, Ancient Corinth

2.1 The Site of Ancient Corinth

The Temple of Apollo at Ancient Corinth is a cornerstone of Greece's cultural and archaeological heritage. Located on the western edge of the agora along the northern slopes of the Acrocorinth, it highlights both the city's religious significance and its central role in civic life (Hellenic Ministry of Culture and Sports, n.d.; Andrikou, 2019).



Figure 1. Panoramic view of the archaeological site of Ancient Corinth and the Acrocorinth.

Source: Athens Voice, (2024).

Ancient Corinth occupies a prominent position at the eastern end of the Gulf of Corinth, at the base of the Acrocorinth, which rises 575 meters above sea level. The urban center sits on a terrace about 90 meters above sea level, roughly 6 kilometers south of the Isthmus of Corinth, linking the Peloponnese to central Greece and separating the

Corinthian and Saronic Gulfs. This location allowed Corinth to control key land and maritime routes, earning it the reputation as one of the “*fetters of Greece*” (Polybius, Histories 18.10-11) and contributing to its economic and political prosperity (American School of Classical Studies at Athens, n.d.; Britannica, n.d.).

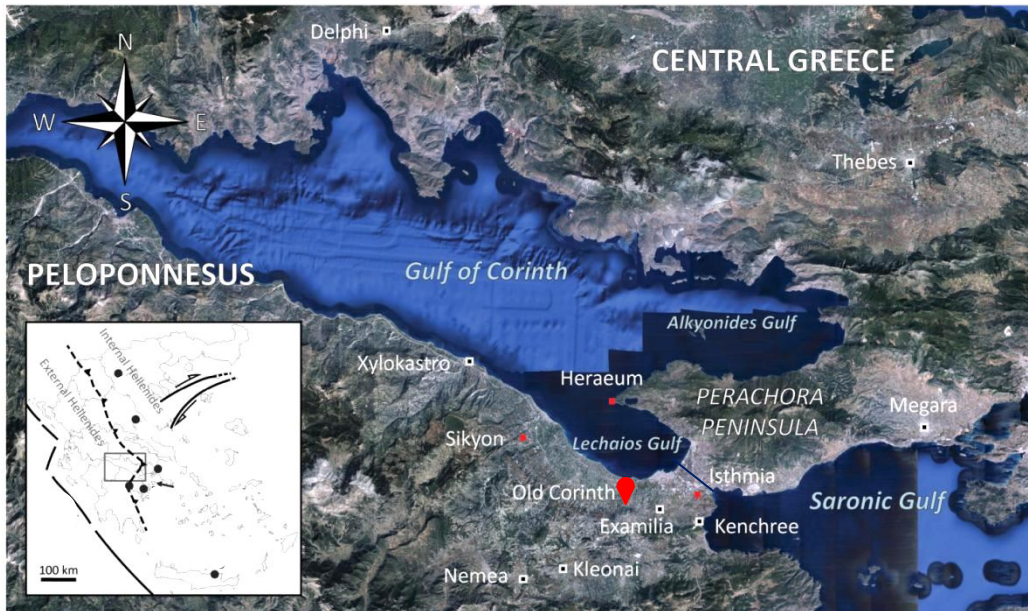


Figure 2. The geographical location of Ancient Corinth and its strategic position near the Isthmus of Corinth

Source: de Vals, M., & Moretti, I. (2022).

Ancient Corinth has maintained a continuous human presence since the Neolithic period. From the Mycenaean era onward, the city grew steadily, becoming a key regional center (Hellenic Ministry of Culture and Sports, n.d.). Its location on the Isthmus, which links mainland Greece to the Peloponnese, provided fertile land, abundant resources, and control over major land and sea routes between the Corinthian and Saronic Gulfs. These factors enabled Corinth to develop into an important urban and commercial hub within the Greek world (Salmon, 1984; Encyclopaedia Britannica, n.d.). By the 8th century BC, the city had established extensive trade networks and founded influential colonies, such as Corcyra and Syracuse, strengthening its influence in the western Mediterranean (Boardman, 1999).

The city reached its zenith in the 7th and 6th centuries BC under Cypselus and Periander, a period marked by economic growth, artistic production, and major public monuments, including the Temple of Apollo (Hellenic Ministry of Culture and Sports, n.d.). Corinth gradually lost prominence to Athens by the end of the 6th century BC

(Encyclopaedia Britannica, n.d.), fell under Macedonian control in 338 BC, and was destroyed by the Romans in 146 BC. It was subsequently revived as a Roman colony in 44 BC under the leadership of Julius Caesar and subsequently designated as the capital of Achaia in 27 BC. The city's early development was characterized by the settlement of freedmen and veterans. Corinth, planned around a monumental forum, thrived as an administrative and commercial center in Roman Greece. It was visited by the Apostle Paul in the mid-1st century AD (Hopper, 1955). Despite later invasions and natural disasters, it remained regionally significant through the Byzantine, Frankish, Venetian, and Ottoman periods (Hellenic Ministry of Culture and Sports, n.d.).

The archaeological remains lie directly south of the modern city, linking Corinth's ancient heritage to its contemporary landscape.

2.2 Archaeological Background of the Temple of Apollo

The Temple of Apollo is a significant exemplar of Archaic Doric architecture in the Peloponnese and mainland Greece (Kissas et al., 2015). The Temple of Apollo at Corinth was founded around 560 BC. It was constructed using local oolitic limestone, bricks, and wooden beams. It featured a heavy and complex four-pitched roof covered with clay tiles (Kissas et al., 2015; Hellenic Ministry of Culture, n.d.).



Figure 3. The Temple of Apollo at Ancient Corinth.

Source: ASCSA, METIS Digital Collections.

Given the monument's extensive antiquity, a variety of hypotheses have been proposed concerning its construction date. Despite minor variations among these suggestions, all proposed chronologies converge within the period between 570–560 and 550 BC. Bookidis' research indicates that the construction of the temple occurred in the early third quarter of the sixth century BC. This date was determined to be the most accurate, based on the analysis of pottery fragments retrieved from the layer of poros chips that are directly associated with the temple's construction. In a subsequent study, Bookidis, in collaboration with Stroud, determined the temple's construction date to be approximately 560 BC (Bookidis & Stroud, 2004; Andrikou, 2019). Winter's analysis of the terracotta roof has provided a date of 550-540 BC, with further indications that the onset of construction may have occurred around 560 BC (Andrikou, 2019).

The temple was excavated in 1896, studied, and subsequently published by Wilhelm Dörpfeld and the American School of Classical Studies at Athens (ASCSA). Its original dedication was initially unknown, and for this reason it was referred to as the “*Old Temple*”. Consequently, a number of scholars have proposed that the dedication was to “*Athena Chalinitis*”. However, a comparative analysis of literary sources, - including “*Greek Anthology 6.212*”, “*Herodotus 3.52*”, “*Plutarch (Aratos 40)*”, and “*Pausanias 2.3.6-2.4.5*”² - alongside the material and architectural evidence, led scholars to identify the sanctuary as dedicated to Apollo (Bookidis & Stroud, 2004). This conclusion is derived from the integration of topographical, archaeological, and textual data, which collectively demonstrate that the Archaic temple occupied a prominent position within the Corinthian civic and religious landscape.

Apollo, the deity from Greek mythology associated with prophecy, music, and civic cult practices, was profoundly intertwined with the religious and social fabric of Greek poleis. In foundational studies on Greek religion, it is argued that religious rituals and sanctuaries functioned as collective institutions within the polis, shaping communal

² Greek Anthology. 6.212.,

Herodotus. Histories. 3.52.,

Plutarch. Aratus. 40.,

Pausanias. Description of Greece. 2.3.6–2.4.5.

identity and reinforcing social cohesion through shared rites and public participation (Burkert, 1985). The dedication of the Archaic temple in Corinth to Apollo therefore not only reflects his religious significance but also underscores the role such cults played in public life, urban organization, and collective identity in the city-state context. The temple's prominent location and substantial size further emphasize Apollo's importance within the urban and economic landscape of Corinth, highlighting the city's status as a major trading hub and politically influential polis during the Archaic period (Bookidis & Stroud, 2004; Whitley, 2001).

The monument has undergone significant transformations over time, reflecting broader historical changes in Corinth. Following the Roman refoundation of the city as Colonia Laus Iulia Corinthiensis in 44 BC, the temple underwent renovations during the first century CE, most likely under Claudius or Nero, to accommodate the imperial cult (Kissas et al., 2015; Hellenic Ministry of Culture, n.d.). In subsequent periods, the Temple Hill persisted in its role as a sacred and urban landmark, as demonstrated by the erection of a Byzantine basilica on its northeastern periphery. While the temple once boasted a substantial number of standing columns, subsequent dismantling over time has left only a limited number of columns and the structural footprint intact (Kissas et al., 2015; Andrikou, 2019). Presently, these preserved elements overlook the excavated Roman Forum of Ancient Corinth and the Archaeological Museum, thereby providing the material basis for examining the architectural form and organization of the Archaic monument (Kissas et al., 2015).

2.3 Architectural Characteristics and Materials

The Archaic Temple of Apollo in Corinth was a Doric peripteral building measuring approximately 53.66 meters long by 21.44 meters wide (Kissas et al., 2015). It was erected on a levelled platform created by cutting into the calcrete layer overlying the bedrock, upon which the stereobate was laid. Portions of the krepidoma remain, and the stylobate survives partially along the western and southern sides of the monument (Andrikou, 2019). As one of the earliest large-scale stone temples of mainland Greece, the structure reflects an experimental yet monumental phase in the development of Doric architecture, expressed through its massive proportions and constructional logic.

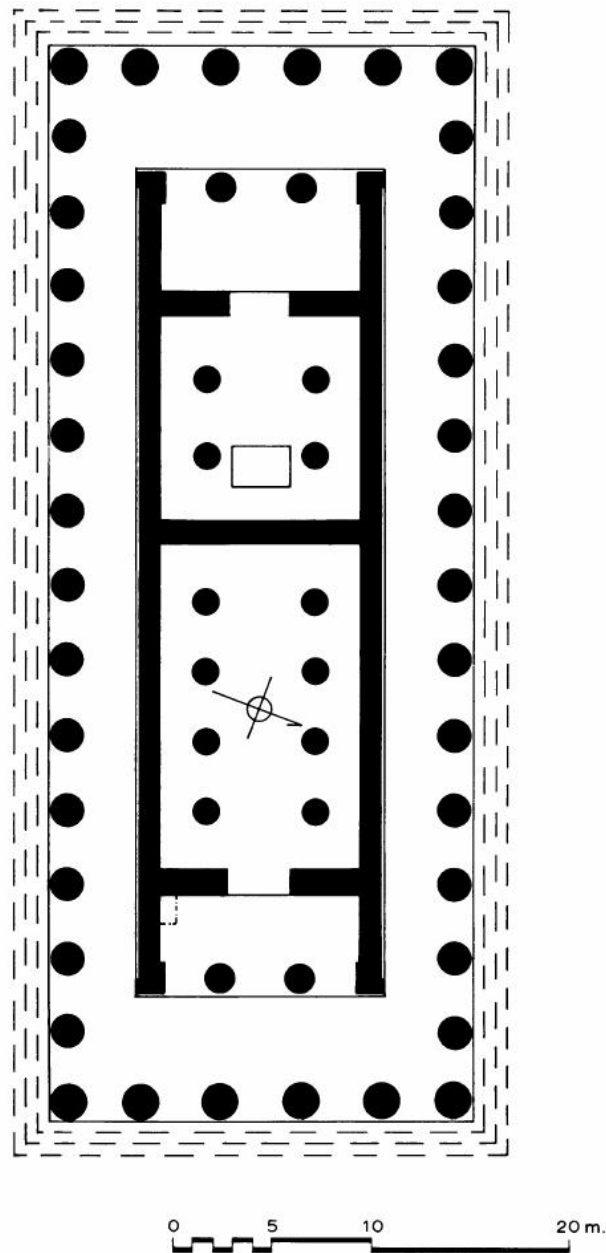


Figure 4. Restored plan of the Temple of Apollo, showing the 6×15 peripteral arrangement and internal spatial organization.

Source: Pfaff (2003).

The pteron consisted of thirty-eight monolithic columns arranged according to the Doric peripteral scheme: six columns on the eastern and western fronts, and fifteen along the northern and southern flanks. Reaching a height of approximately 7.26 m, the columns were surmounted by Doric capitals and articulated with twenty flutes. Their lower

diameters averaged about 1.64 m on the flanks and were slightly greater on the façades, enhancing the monumentality of the structure and suggest an early response to the structural demands of large-scale roofing (Kissas et al., 2015; Andrikou, 2019). Today, only seven columns remain standing in situ: five on the western front and two on the southern side near the southwestern corner.

Only four epistyle blocks of the superstructure remain in situ, and no substantial elements of the Doric frieze have been preserved. A single small triglyph fragment was recovered during excavation (Kissas et al., 2015; Andrikou, 2019). Despite the extensive loss of the superstructure, the preserved foundations, column remains, and bedrock cuttings allow for a reliable reconstruction of the temple's footprint and general spatial organization. Engraved guide marks within the foundation trenches suggest a probable transverse division of the cella into two chambers, a feature that may relate either to structural requirements for supporting the heavy roof or to differentiated cultic functions, although such interpretations remain necessarily hypothetical given the fragmentary state of preservation (Andrikou, 2019; Scahill, 2017).

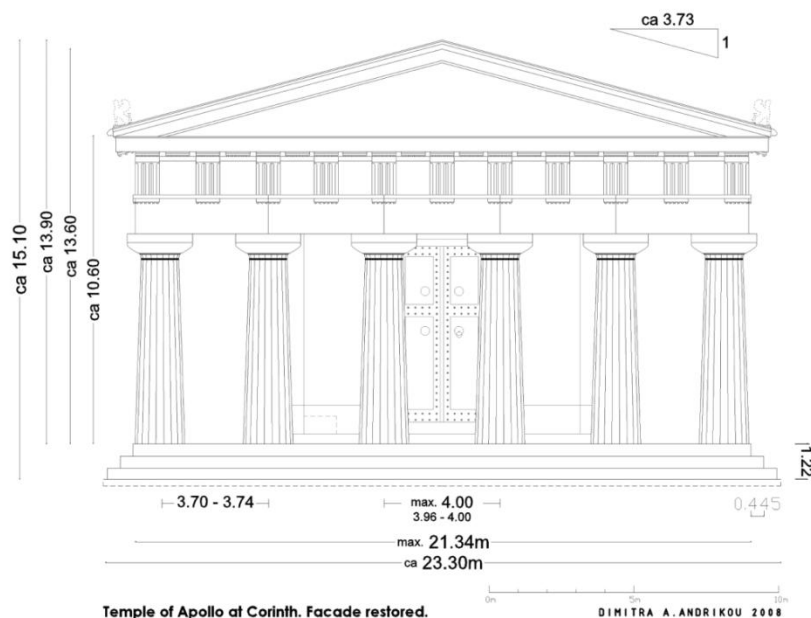


Figure 5. Temple of Apollo at Corinth, graphical reconstruction of the façade.

Source: Andrikou (2019).

2.3.1 Architectural Analysis

The architectural character of the Temple of Apollo constitutes an early and monumental manifestation of the Doric order, reflecting the formative stages of Archaic stone temple construction. The design of the building emphasizes mass, solidity, and structural clarity. These qualities are closely associated with early Doric architecture. The substantial diameter of the columns, in relation to their height, fosters an impression of weight, permanence, and stability, thereby amplifying the monument's commanding presence within the Corinthian landscape (Kissas et al., 2015; Andrikou, 2019).

A distinguishing characteristic of the temple is the presence of a double internal colonnade within the cella. Beyond its spatial organization, this arrangement has been interpreted as a structural strategy devised to support the substantial load of a heavy, multi-pitched roof system. This strategy thus illustrates an experimental phase in large-scale stone architecture. These solutions underscore the transitional nature of Archaic building practices, situated between earlier timber-based construction traditions and the more codified architectural forms characteristic of the mature Doric order (Andrikou, 2019). The proposed spatial organization is illustrated in Figure 6.

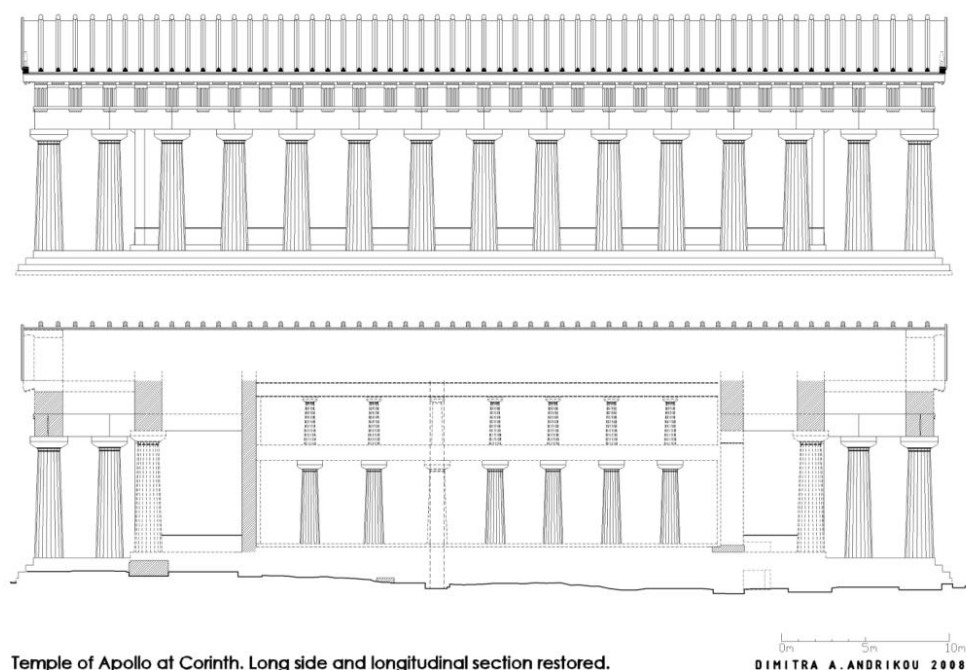


Figure 6. Temple of Apollo at Corinth, graphical reconstruction of the long side and longitudinal section.

Source: Andrikou (2019).

The architectural restraint and austerity exhibited by the monument are of equal significance. The dearth of compelling evidence for sculptural embellishment, compounded by the absence of a preserved Doric frieze, suggests that the emphasis was directed towards the structural form, proportion, and tectonic logic of the edifice rather than its ornamental richness. Due to the fragmentary state of preservation, modern interpretations of the temple's original appearance rely extensively on archaeological reconstruction and comparative architectural analysis, as presented in various studies related to reconstruction methodologies in Ancient Corinth (Scahill, 2017; Kissas et al., 2015; Frampton, 1995).

Consequently, the temple's monumental form, structural clarity, and tectonic logic are closely associated with the properties of the stone utilized (Frampton, 1995). The durability and strength of local materials enabled the construction of a double internal colonnade, a heavy roof, and a sense of solidity and permanence. Therefore, a comprehensive understanding of these materials is instrumental for the effective execution of architectural design.

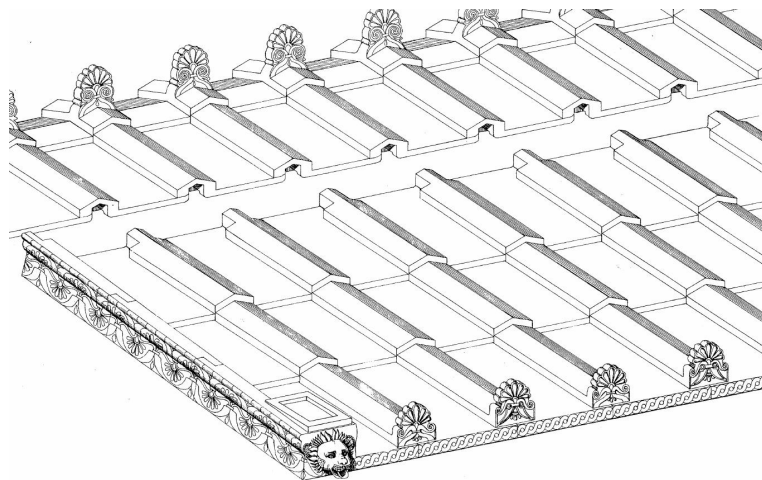


Figure 7. Reconstruction of the roof of the Temple of Apollo.

Source: Pfaff (2003).

2.3.2 Construction Materials

The construction of the Temple of Apollo at Corinth employed a combination of locally available materials, including oolitic limestone, mud brick, timber, and terracotta roofing elements, reflecting the availability of regional resources and the technological

practices of the Archaic period (Rhodes, 2003; Pfaff, 2003; Kissas et al., 2015; Hayward, 2003).

Oolitic limestone was one of the principal construction materials used in Corinthian monumental architecture. Hayward (2003) highlights the importance of local geological resources in ancient Corinthian construction and documents the extensive exploitation of limestone in the Corinthian landscape, including the Temple Hill area. Hayward (1996) further describes Corinthian oolitic limestone as a relatively soft, fine-grained, beige carbonate stone that was extensively quarried in antiquity and widely used at Ancient Corinth, as well as at regional sites such as Delphi, Epidauros, and Perachora. Petrographic analysis of the Examilia quarry line demonstrated that, despite the stone's macroscopically uniform appearance, significant microscopic variation exists, allowing differentiation between quarry sources within the Corinthia (Hayward, 1996). These findings further support the interpretation that local quarry resources were systematically exploited for monumental architectural construction.

The temple was erected on a carefully prepared platform created by cutting into the calcrete overlying the bedrock, providing a stable base for the stereobate and the substantial stone superstructure (Kissas et al., 2015; Andrikou, 2019). As a monumental Archaic Doric structure, the temple required the coordinated use of masonry, timber construction, and ceramic roofing technology (Rhodes, 2003; Pfaff, 2003).

The terracotta roofing system would have introduced considerable structural loading requirements, influencing the architectural design and the arrangement of supporting elements (Sapirstein, 2009). The integration of stone masonry, timber structural members, and ceramic roofing components demonstrates the technological sophistication and material coordination characteristic of Archaic monumental architecture (Rhodes, 2003).

2.4 Previous Conservation Interventions

The Temple of Apollo had previously been the subject of early conservation activity. Scahill observes that, despite its prominence among the monuments of ancient Corinth, the temple has not undergone extensive reconstruction in modern times, with much of the surviving structure remaining in situ rather than being rebuilt.

The initial documented conservation intervention took place in 1908, when a fractured epistyle block at the preserved western end of the temple was stabilized. The condition of the monument has been documented through archival photographs both before and after the initial intervention (Scahill, 2017).



Figure 8. Temple of Apollo at Ancient Corinth: (a) condition before the 1908 restoration; (b) condition after restoration.

Source: ASCSA, METIS Digital Collections.

Additional interventions were executed in the 1930s under the auspices of *“the Greek Archaeological Service”*, encompassing the stabilization of the krepidoma. Concurrently, cement was applied to the upper surfaces of epistyle blocks and column capitals, and sections of column shafts were patched with mortar. It is noteworthy that one column may have undergone subsequent treatment as late as the 1940s (Scahill, 2017).

According to the archives of the ASCSA at Corinth, a systematic examination of the architectural members was carried out in 1970 and 1971 by *“the Service of Antiquities”* under the supervision of Mr. Solomides, then Director of the Service. Concurrently, Joseph Shaw prepared precise, measured drawings of the area, thereby making a substantial contribution to the documentation of the monument's state of preservation.



Figure 9. The Temple of Apollo at Ancient Corinth during an early phase of conservation works, with scaffolding erected around the surviving architectural elements.

Source: ASCSA, METIS Digital Collections.

The investigation was conducted following a diagnostic documentation approach, integrating selective cleaning, direct visual examination, measured recording, and systematic photographic documentation of joints, bedding surfaces, and individual structural members (Corinth Notebook Page NB 429 - ASCSA.net, n.d.).

During the 1970 campaign, evidence for multiple intervention phases was identified. Specifically, two distinct phases were recognized: a Roman phase and a later modern phase, which may have occurred around 1930. The identification was based on three factors: material differentiation, constructional characteristics, and joint morphology.

Roman mortar was identified in numerous joints of the architraves, epistyles, stylobate, and krepis, particularly in lower horizontal bedding joints. Its distribution indicates a coherent phase of structural repair or reinforcement, most likely during the Roman period, although the precise extent and circumstances of this intervention remain uncertain. Furthermore, evidence of clamp cuttings was also observed on specific architectural elements. Nevertheless, the available documentation does not provide conclusive evidence to support the hypothesis of Roman re-lifting of the epistyle blocks (Corinth Notebook Page NB 429 - ASCSA.net, n.d.).

In addition, the 1970 campaign included the selective removal of modern cement from specific epistyle joints (particularly between blocks C-D, D-F, and B-C), as well as from selected portions of upper bedding surfaces. The objective of this procedure was to

facilitate precise observation, photographic documentation, and recording of the original contact surfaces. Thus, it was determined that cement mortar had been extensively applied in both vertical and horizontal joints, frequently obscuring the original construction interfaces (Corinth Notebook Page NB 429 - ASCSA.net, n.d.).

The 1971 campaign was chiefly concerned with re-examining and confirming the observations made during the previous year, with a particular emphasis on the north epistyle and its associated joints. An additional cleaning procedure was performed on select upper bedding surfaces. This was done to assess their morphology and to determine the preservation of potential construction cuttings (Corinth Notebook Page NB 429 - ASCSA.net, n.d.).

The reinspection confirmed extensive deterioration of the upper surfaces, characterized by pronounced granular disintegration and deep weathering. This condition considerably complicated the reliable identification of construction details. A thorough examination of the epistyle surfaces revealed no evidence of clearly preserved U-shaped lifting cuttings. However, the presence of small square vertical holes was observed near the interior corners of specific blocks. These cuttings were considered insufficient for primary lifting and may instead be associated with auxiliary handling or stabilization mechanisms.

Dimensional measurements were undertaken to record the geometry of the architectural members and identify possible dimensional inconsistencies. Minor variations were observed among the epistyles, with an average height of approximately 0.60 m, while erosion of the arrises affected measurement precision. A comparison of the exterior surfaces with the interior surfaces revealed that the former exhibited more advanced weathering (Corinth Notebook Page NB 429 - ASCSA.net, n.d.).

At the conclusion of the 1971 campaign, no structural displacement or active instability was observed. Despite the presence of multiple intervention phases and substantial surface deterioration, the monument was determined to be structurally stable during the period of documentation (Corinth Notebook Page NB 429 - ASCSA.net, n.d.). Consequently, the 1970-1971 campaigns yielded pivotal evidence, not only for comprehending the monument's conservation history but also for elucidating its constructional and structural behavior.

2.5 Environmental and Geological Context

The Temple of Apollo is located in the north-eastern Peloponnese, in the vicinity of the southern end of the Gulf of Corinth, an area which is considered to be one of the most tectonically active regions of the eastern Mediterranean (Figure 10) (Antonakos, 2012). The broader geological framework of the region is defined by extensional tectonics associated with the Corinth Rift system, a zone characterized by frequent seismicity and active normal faulting that has shaped both the landscape and the seismic hazard profile over millennia (Armijo et al., 1996; Jackson & McKenzie, 1988). The tectonic configuration of the rift exerts a strong control over regional geomorphology, influencing drainage networks, sediment transport, and coastal evolution along the Gulf of Corinth (Perrou et al., 2013).

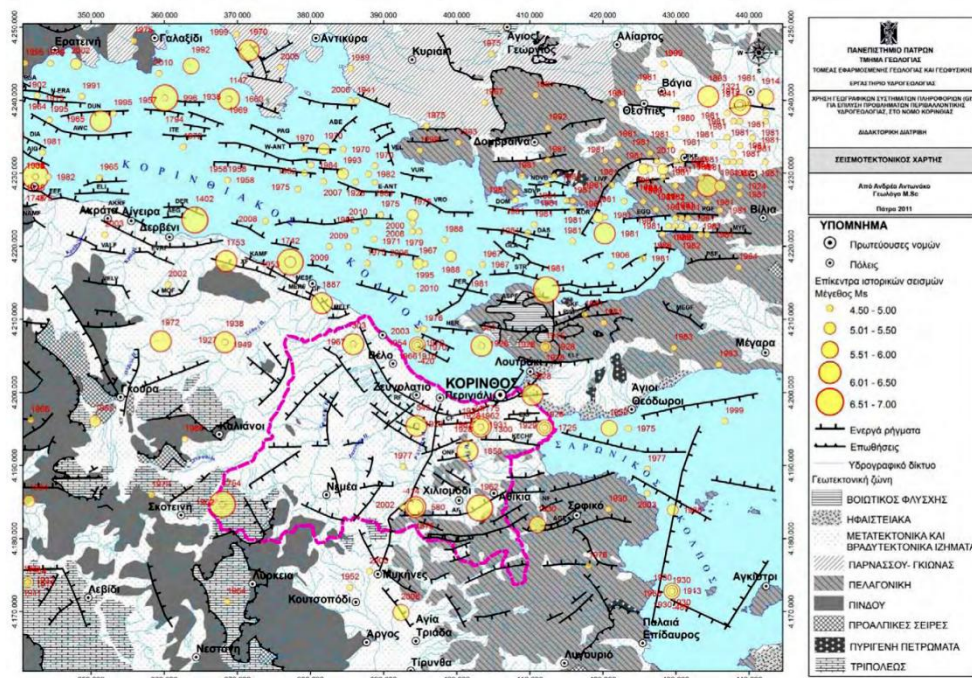


Figure 10. Seismotectonic map of the wider Corinthian region, showing historical earthquake epicentres and major active faults.

Source: Antonakos (2012).

The regional geology of the Corinthian region is characterized by the predominance of sedimentary carbonate formations, comprising various limestone units and associated shallow-marine deposits (Figure 11) (Antonakos, 2012). The abundance of carbonate rocks in the northeastern Peloponnese suggests that these materials constituted an important local resource for the construction of numerous ancient structures in the

region. Specifically, the Temple of Apollo was constructed using oolitic limestone, one of the principal building materials employed in Corinthian monumental architecture (Hellenic Ministry of Culture, n.d.; Hayward, 1996). As a carbonate building stone, its durability and response to environmental stressors are influenced by its physical and chemical characteristics, particularly pore structure, mineral composition, and weathering behaviour, which are key factors in long-term deterioration processes (Siegesmund & Snethlage, 2016).

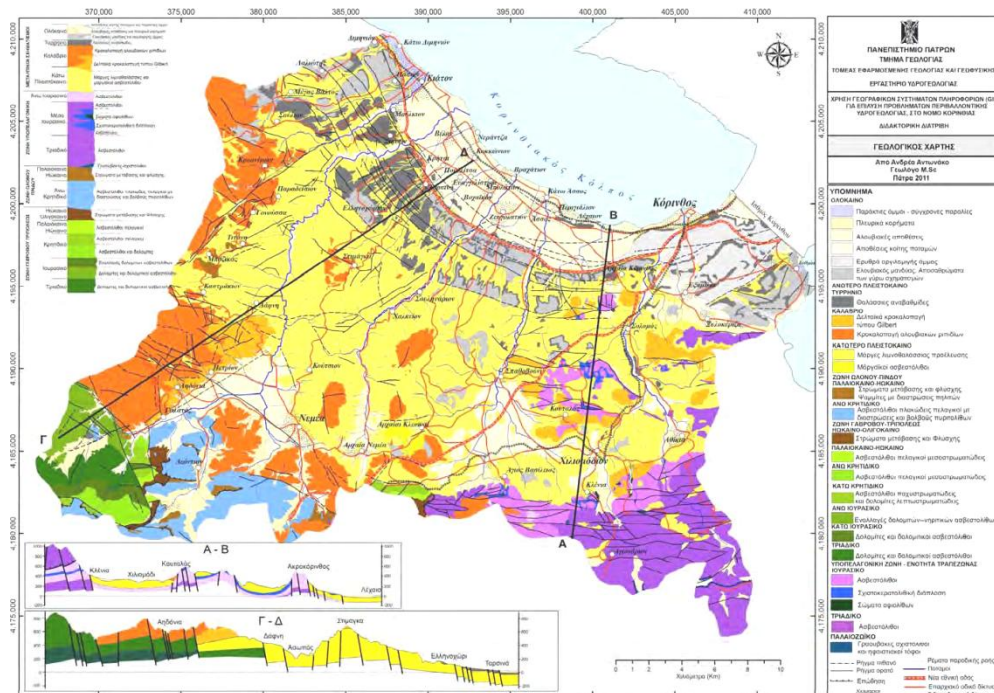


Figure 11. Geological map of the Corinthian region showing the distribution of the main geological formations and representative geological sections.

Source: Antonakos (2012).

The deterioration patterns observed on the exposed surfaces of the temple are consistent with weathering mechanisms commonly affecting carbonate building stones under Mediterranean climatic conditions (Charola, 2000; Siegesmund & Snethlage, 2016). The Mediterranean climate is typified by *“hot, dry summers and wet, cool winter”* (Ciric et al., 2018). Such conditions promote repeated thermal expansion and contraction of exposed stone surfaces, while seasonal fluctuations in rainfall and relative humidity facilitate moisture ingress, salt migration, and crystallization within the limestone fabric, contributing to long-term material deterioration (Siegesmund & Snethlage, 2016).

Hydrological processes also influence the weathering of the monument and the surrounding geomorphological environment. Seasonal rainfall and surface runoff affect moisture availability in nearby soils and exposed architectural surfaces, facilitating the transport of dissolved salts and other weathering agents into the limestone fabric (Charola, 2000). Subsequent evaporation during the dry summer season enhances salt crystallization, contributing to granular disintegration and progressive material deterioration of the stone (Charola, 2000; Siegesmund & Snethlage, 2016).

At a regional scale, the tectonic framework of the Corinth Rift system significantly influences hydrological processes in the northeastern Peloponnese by regulating drainage patterns and groundwater circulation within fractured carbonate formations (Antonakos, 2012). Groundwater movement is largely controlled by fault structures and fracture networks, while episodic surface runoff and local water infiltration contribute to fluctuating moisture conditions in the surrounding environment. These hydrological dynamics may indirectly influence deterioration processes by affecting moisture availability and weathering conditions around exposed architectural surfaces (Antonakos, 2012; Charola, 2000).

The elevated and exposed position of the temple intensifies its exposure to environmental stressors. Its orientation toward the northern sector, facing the Gulf of Corinth, increases its vulnerability to marine and atmospheric influences. Exterior stone surfaces are directly exposed to solar radiation, prevailing winds, marine aerosol transport from the gulf, and airborne pollutants originating from the industrial area of Corinth. These environmental factors contribute to more pronounced weathering on the outer architectural surfaces compared to the interior facades, a pattern observed during the 1971 documentation (Corinth Notebook Page NB 429, ASCSA.net, n.d.).

In addition, anthropogenic factors, including atmospheric pollution and visitor-related mechanical wear, may further contribute to the deterioration of the monument through chemical and physical degradation processes affecting limestone surfaces (Brimblecombe, 2003; Charola, 2000).

Thus, the preservation of the monument is influenced by a multifaceted array of environmental stressors, encompassing the geological substrate, tectonic activity, climatic conditions, hydrological processes, and human influences. However, recent research

suggests that ongoing climate change in the Mediterranean region may amplify the impact of various deterioration mechanisms. Specifically, in stone-built heritage sites, rising temperatures, increasing climatic variability, and changes in precipitation patterns are predicted to affect moisture regimes and accelerate weathering processes (Kapsomenakis et al., 2022; IPCC, 2021). These emerging climate challenges underscore the imperative to take future environmental scenarios into account when assessing the long-term preservation of the temple.

3 Climate Change Impacts on Cultural Heritage

3.1 General Framework

Climate change has emerged as one of the most significant environmental challenges of the modern era. It refers to long-term changes in the Earth's climate system, including variations in temperature, precipitation patterns, and the frequency and intensity of extreme weather events. According to the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as *“a change in climate that is directly or indirectly attributable to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods”* (UNESCO, 2008).

The scientific assessment and global monitoring of climate change involve various international organizations, including the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization (WMO), the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Educational, Scientific and Cultural Organization (UNESCO). These organizations play a pivotal role in evaluating climate trends, assessing environmental impacts, and developing strategies for mitigation and adaptation, including the protection of cultural and natural heritage.

Climate change therefore poses complex challenges for both natural and cultural systems. Cultural heritage sites, particularly archaeological monuments exposed to open-air environmental conditions, are increasingly vulnerable to climate-related stressors that accelerate deterioration processes and threaten their long-term preservation. Consequently, the preservation of these sites entails not only the protection of their physical integrity but

also the safeguarding of their cultural identity and the transmission of their cultural and natural heritage to posterity (IPCC, 2022; UNESCO, 2007).

The impact of climate change on cultural heritage is multifaceted, involving a series of interactions between climatic drivers, environmental processes, and the materials used in the construction of monuments. The deterioration of archaeological materials can be accelerated by “*physical, chemical, and biological processes*” triggered by changes in temperature, precipitation, and humidity. These changes, in turn, are influenced by the increasing occurrence of extreme weather events. Consequently, a relationship is established between climate drivers and environmental processes, as well as their subsequent impacts on cultural heritage sites (Sesana et al., 2021). As demonstrated in **Table 1**, a framework has been developed to illustrate the manner in which climate-related factors can result in material degradation, thereby endangering the conservation of cultural heritage.

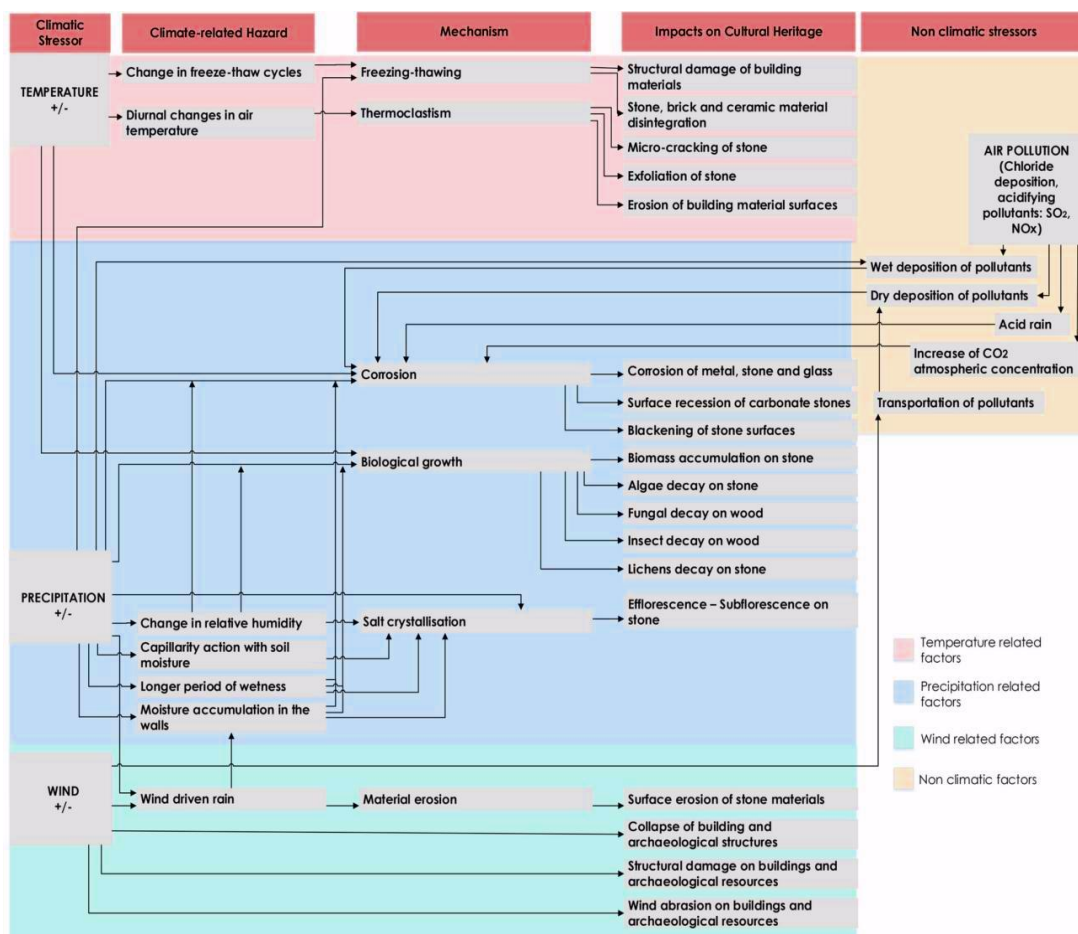


Table 1. Conceptual framework linking climatic stressors, environmental mechanisms and impacts on cultural heritage materials (Sesana et al., 2021).

Specifically, the framework illustrates how variations in key climatic factors, such as temperature, precipitation, and wind, can trigger deterioration mechanisms affecting cultural heritage materials. Temperature fluctuations have been shown to induce freeze-thaw cycles and thermoclastic processes, leading to micro-cracking, exfoliation, and the gradual disintegration of stone and ceramic materials. Changes in precipitation and relative humidity have been shown to increase moisture accumulation in building materials, thereby promoting processes such as salt crystallization, corrosion, and biological colonization. In addition, wind-related processes such as wind-driven rain and wind abrasion may contribute to surface erosion and mechanical damage to exposed monument surfaces.

Thus, it is imperative to comprehend the intricate interplay among climatic elements, environmental processes, and material properties to accurately assess the vulnerability of cultural heritage sites and formulate efficacious conservation strategies. Consequently, the following sections provide a comprehensive exposition on the main environmental stressors associated with climate change and their implications for historic materials.

3.2 Climate-Related Hazards and Stressors

3.2.1 Temperature and Humidity Variability

Temperature and relative humidity are among the most significant environmental factors affecting the preservation of cultural heritage materials. Climate change is expected to lead to higher average temperatures, as well as increased variability in temperature and humidity patterns, particularly in regions that are highly sensitive to climate change, such as the Mediterranean basin (IPCC, 2022; Giorgi & Lionello, 2008). As atmospheric humidity is closely related to temperature, changes in air temperature under global warming conditions are expected to influence water vapor levels (Hao & Lu, 2022). These environmental fluctuations have the potential to significantly impact the physical and chemical durability of materials commonly used in monuments, such as limestone, marble, brick, and mortar (Sesana et al., 2021).

Thermal variations have been observed to induce recurrent cycles of expansion and contraction in stone materials. Brimblecombe and Grossi (2007) posit that, over time,

these cycles generate internal mechanical stresses that can result in micro-cracking, exfoliation, and granular disintegration of stone surfaces. Such deterioration processes are most evident in porous materials, where temperature fluctuations can impact evaporation rates and promote the crystallization of soluble salts within the pore structure.

Relative humidity (RH) is also a significant factor in material degradation processes. Variations in humidity influence the absorption and release of moisture within stone materials, affecting both chemical reactions and biological growth. High levels of environmental moisture promote the colonization of microorganisms such as algae, fungi, and lichens. In addition, repeated wet-dry cycles accelerate salt crystallization processes, which can damage the internal structure of stone materials (Sesana et al., 2021). Consequently, fluctuations in temperature and humidity can affect multiple physical, chemical, and biological deterioration mechanisms in stone materials. These processes include thermal expansion, salt crystallization, moisture cycles, and biological colonization.

In Mediterranean climates, marked by hot summers and relatively humid winters, projected increases in temperature and changes in moisture regimes may intensify these deterioration mechanisms. Regional climate projections indicate that temperatures in Greece and the eastern Mediterranean region are expected to undergo a substantial increase during the twenty-first century, accompanied by an increased frequency of heat extremes and extended periods of drought (Politi et al., 2023; Tringa et al., 2025). The spatial distribution of projected changes in maximum temperature across Greece is presented in Figure 12 (Politi et al., 2023). Consequently, monuments exposed to external environmental conditions may undergo increased material stress and accelerated weathering processes. Thus, beyond temperature and humidity variability, precipitation-related processes also play a critical role in material deterioration.

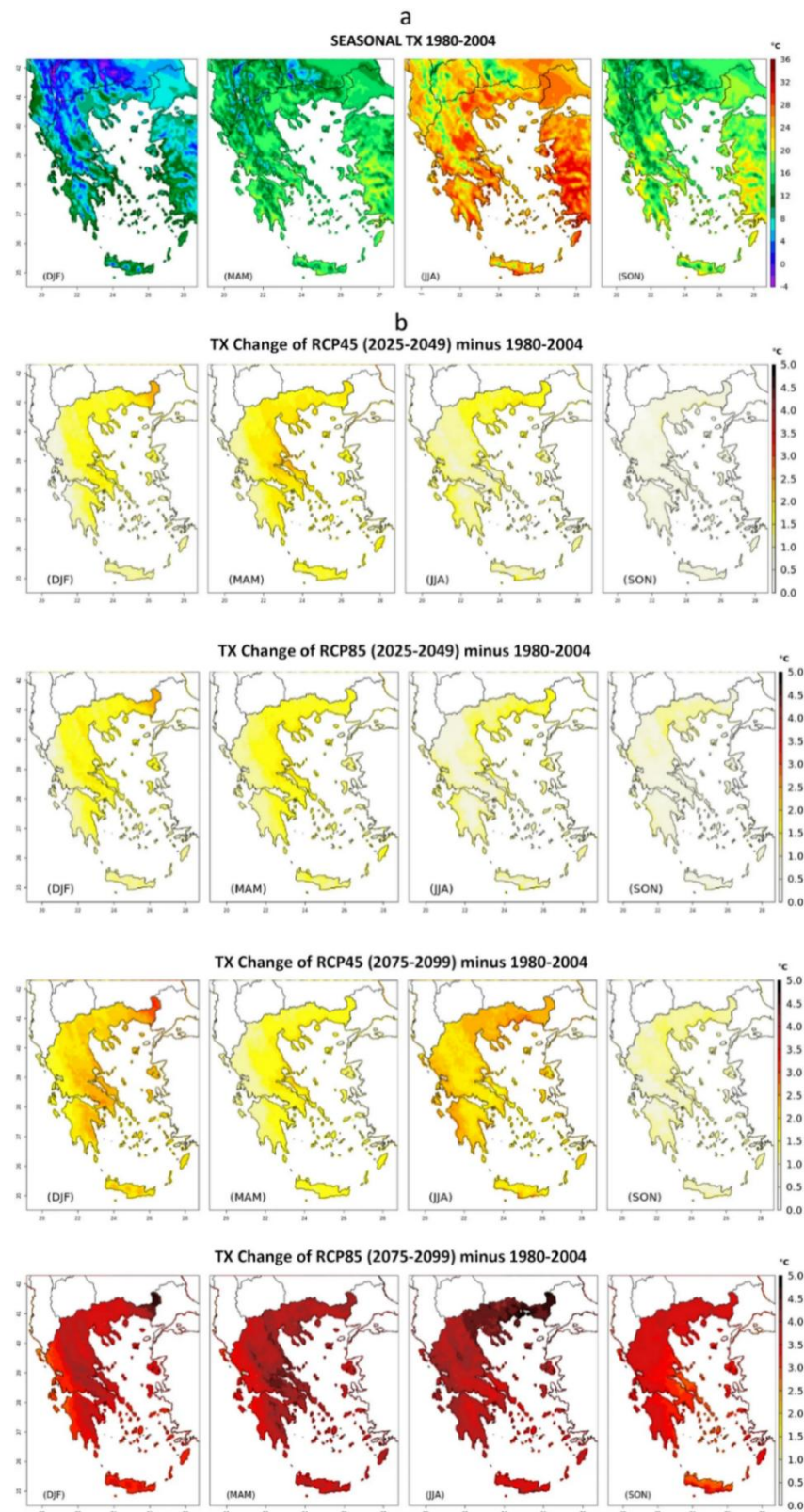


Figure 12. Seasonal distribution of maximum temperature (TX) during the historical period (1980–2004) and projected changes in maximum temperature for the near future (2025–2049) and far future (2075–2099) under the RCP 4.5 and RCP 8.5 climate scenarios over Greece.

Source: Politi et al. (2023).

3.2.2 Precipitation and Hydrological Effects

Changes in precipitation patterns represent another important factor influencing the preservation of cultural heritage sites. Climate projections indicate that many regions will experience alterations in both the intensity and frequency of rainfall events, including more frequent extreme precipitation as well as prolonged drought periods (IPCC, 2022).

In particular, cultural heritage structures are subject to the effects of the environment, and shifts in precipitation patterns have the capacity to modify the microclimate of the outdoor environment surrounding monuments and archaeological landscapes. Variations in rainfall intensity and frequency influence environmental parameters such as relative humidity, soil moisture, and water penetration. These factors have been demonstrated to impact the longevity of building materials such as stone, brick, and mortar, which are frequently utilized in historic structures and are highly sensitive to moisture-related degradation (Tringa et al., 2025, Markantonis et al., 2025).

Rainwater infiltration into porous construction materials has been demonstrated to initiate a variety of deterioration mechanisms. Water has the capacity to dissolve soluble salts that are present in building materials or surrounding soils, thereby facilitating their movement through the pore network of stones. During subsequent drying phases, salt crystallization may occur within the pores, generating internal stresses that can lead to microcracking, scaling, and granular disintegration of the stone surface. In addition, extended exposure to moisture has been demonstrated to expedite chemical weathering reactions and augment the vulnerability of materials to biological colonization (Markantonis et al., 2025; Sesana et al., 2021).

Hydrological processes associated with precipitation encompass wind-driven rain, flooding, and fluctuations in groundwater level (Ciric et al., 2018; Markantonis et al., 2025). Wind-driven rain substantially augments the moisture load on exposed monuments lacking protective barriers. Furthermore, flooding can lead to the prolonged saturation of building materials and structural damage, while groundwater variability can affect foundations and subsurface archaeological remains (Markantonis et al., 2025; Sesana et al., 2021). These processes may contribute to structural instability and surface deterioration of in-situ heritage elements.

Regional climate projections indicate that precipitation patterns in Greece will become increasingly variable under future climate scenarios. Total precipitation is expected to decrease, likely leading to drought conditions and elevated wildfire risk. Nevertheless, precipitation is not expected to cease entirely. Instead, rainfall events are projected to occur less frequently but with greater intensity (Politi et al., 2023). The projected changes in precipitation patterns in Greece are illustrated in Figure 13 (Politi et al., 2023).

In parallel, research on atmospheric moisture transport highlights the important role of the Mediterranean Sea as a key source of water vapor, contributing to both climatological precipitation and the intensification of extreme events in surrounding continental regions (Ciric et al., 2018). Although the Mediterranean is not always the primary source of precipitation, it becomes particularly critical during extreme weather events (Ciric et al., 2018). This highlights the increasing importance of understanding hydrological processes when assessing climate-related risks to cultural heritage in Mediterranean environments.

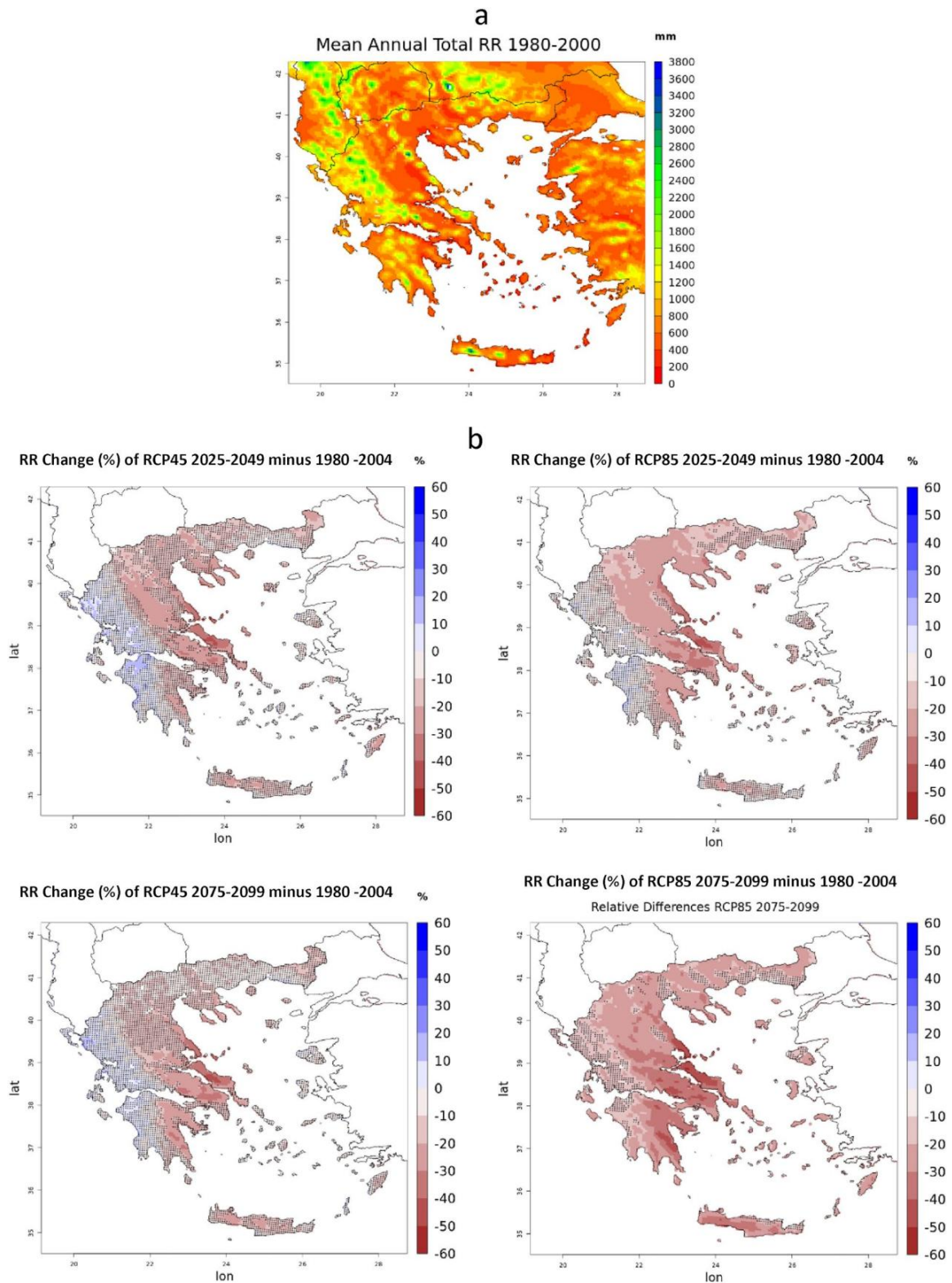


Figure 13. Mean annual total precipitation and projected changes in precipitation over Greece under the RCP4.5 and RCP8.5 climate scenarios.

Source: Politi et al. (2023).

3.2.3 Air Pollution and Atmospheric Deposition

Air pollution is a major factor contributing to the degradation of cultural heritage. Environmental parameters such as temperature, humidity, and rainfall influence both material properties and the processes governing the transport and deposition of pollutants on monument surfaces.

In urban and industrial areas, where pollutant concentrations are elevated, air pollution poses a significant environmental threat (Brimblecombe, 2003). It consists of a complex mixture of gaseous and particulate pollutants that adversely affect environmental quality, human health, and material integrity. The primary pollutants include carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen oxides (NO_x), ozone (O₃), particulate matter (PM), and lead (Pb), mainly originating from anthropogenic activities such as fossil fuel combustion (Vallero, 2014).

The interaction between air pollution and climate change is particularly critical. Rising temperatures accelerate atmospheric reactions, enhancing the formation of secondary pollutants (IPCC, 2022). At the same time, changes in precipitation patterns influence deposition processes by either limiting the natural cleaning of surfaces or facilitating the penetration of acidic solutions into porous materials (Sesana et al., 2021). Moreover, increased temperatures intensify photochemical reactions in the atmosphere, leading to higher production of ground-level ozone and fine particles. In addition, phenomena such as wildfires, desertification, and increased dust transport contribute to elevated concentrations of airborne particulate matter (Vallero, 2014).

Air pollution significantly affects archaeological materials, which constitute valuable cultural heritage. Pollutants such as sulfur dioxide and nitrogen oxides undergo atmospheric transformations, enhanced by environmental conditions (particularly elevated temperatures) leading to the formation of acidic compounds, including sulfuric and nitric acids (Vallero, 2014).

These acidic compounds are deposited on material surfaces through wet and dry deposition processes. This deposition represents a key mechanism through which pollutants interact with cultural heritage materials, influencing both the rate and type of deterioration (Vallero, 2014; Sesana et al., 2021).

Carbonate rocks, such as limestone and marble, are particularly vulnerable. Sulfur dioxide reacts with calcium carbonate in the presence of moisture, forming gypsum, a soluble compound that weakens the material structure (Vallero, 2014). This process leads to the formation of black crusts, especially on sheltered stone surfaces where pollutants accumulate. These crusts incorporate particulate matter and may eventually detach, resulting in loss of surface detail, material loss, and surface deterioration (Skoulikidēs, 2000).

Particulate matter also plays a significant role in degradation processes, as it accumulates on surfaces, causing discoloration and promoting chemical reactions that accelerate weathering (Vallero, 2014). Additionally, deposited particles enhance moisture retention on porous substrates, further intensifying deterioration processes (Brimblecombe, 2003).

Although air pollution levels have declined in many European countries due to environmental regulations, the combined effects of pollutants and changing climatic conditions continue to pose a significant threat to the preservation of cultural heritage.

In addition to anthropogenic air pollutants, marine aerosols constitute an important factor affecting the deterioration of cultural heritage, particularly in coastal or near-coastal environments such as the Temple of Apollo, which is located approximately 3 km from the coastline. Sea spray contains dissolved salts, primarily sodium chloride (NaCl), which can be transported inland by wind and deposited on monument surfaces, with deposition rates decreasing with distance but remaining significant several kilometers from the shore (Charola, 2000; Feliu et al., 1999).

These salts penetrate porous materials such as limestone through capillary action. Under fluctuating environmental conditions, especially changes in relative humidity, salt crystallization and dissolution cycles occur within the pore structure. This process generates mechanical stress, leading to micro-fracturing, granular disintegration, and surface scaling (Theoulakis & Moropoulou, 1999; Scherer, 2004; Charola, 2000).

Consequently, the interaction between atmospheric pollutants and marine aerosols represents a critical factor in assessing the long-term deterioration risk of stone-built cultural heritage in near-coastal environments.

3.2.4 Seismic Activity and Compound Hazards

Climate change is just one of several factors contributing to the degradation of cultural heritage. In the Mediterranean region, environmental pressures in combination with geological hazards, such as seismic activity, further increase the vulnerability of monuments (Fatoric & Seekamp, 2017). The interaction between climatic and geodynamic processes leads to compound hazards that intensify the impact on cultural heritage sites (Kapsomenakis et al., 2022).

The Mediterranean basin is among the most active geodynamic regions worldwide. Although earthquakes are mainly caused by the movement of lithospheric plates, environmental conditions may influence the response of geological systems at local scales (Simon et al., 2025). For instance, variations in water load, groundwater levels, or surface processes may affect stress distribution along faults, potentially influencing seismic behaviour, although they are not considered primary drivers of seismicity.

In Greece, the convergence of the African and Eurasian plates results in the highest seismic activity of any European nation. Seismicity exhibits significant spatial variations, with the Ionian Sea, the South Aegean, and the Gulf of Corinth demonstrating high risk (Tsapanos, 2003). Contemporary estimations corroborate heightened ground acceleration values in the aforementioned regions, which are duly considered in anti-seismic design (Greek regulatory frameworks, including Greek Seismic Code EAK 2000 (EAK 2003) and the European EuroCode-8 standards) (Figure 14) (Pitilakis et al., 2024).

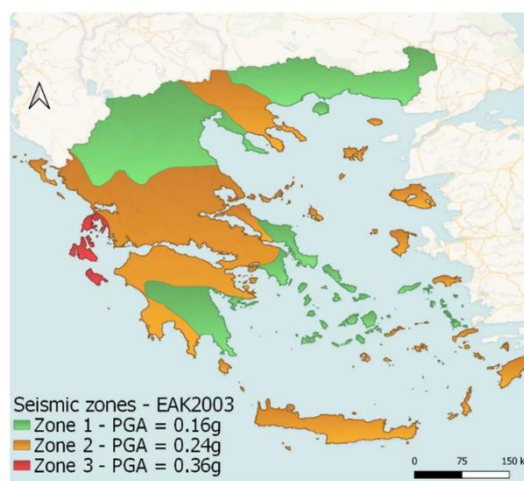


Figure 14. Current seismic hazard zonation map for Greece.

Source: Pitilakis et al. (2024).

A representative example is the Corinth Rift, an area of significant tectonic activity in Europe, where crustal extension is evident in the form of normal faults and recurrent seismic events (Armijo et al., 1996). Seismic activity has been shown to be associated with geomorphological processes, such as subsidence, landslides and sediment liquefaction, which can significantly affect ground stability and landscape evolution (Perrou et al., 2013). The Corinthian region contains a multitude of cultural heritage sites, a fact that merits attention.

Specifically, earthquakes can cause serious structural damage through ground shaking, foundation displacement, and collapse of architectural elements. Cultural monuments are particularly vulnerable, as they were built using traditional techniques that were not designed to withstand strong seismic loads. Concurrently, the concept of complex hazards assumes particular significance, as multiple environmental factors can interact and exacerbate the structural limitations of monuments (Despotaki et al., 2018; Kapsomenakis et al., 2022). For instance, heavy rainfall following a seismic event can destabilize weakened structures, while prolonged drought conditions may affect soil stability and increase the vulnerability of foundations. For this reason, cultural heritage requires systematic documentation, continuous monitoring, and integration into risk management and resilience strategies to ensure its long-term protection (ICOMOS, 2019). Overall, the Corinth region represents a characteristic example of an area where seismic activity and climate-related processes interact, increasing the risk of damage to cultural heritage sites in seismically active regions (Despotaki et al., 2018).

4 Monument Vulnerability and Exposure Assessment

The Temple of Apollo is a cultural monument that has been, and will continue to be, exposed to environmental and climatic hazards over time. Consequently, as a preliminary step in the development of a risk assessment framework, its vulnerability and exposure to these hazards must be evaluated. Vulnerability refers to the susceptibility of the monument to deterioration resulting from its material properties, structural characteristics, and state of conservation, while exposure denotes the extent to which it is subject to environmental, geological, and anthropogenic stressors (ICOMOS, 2019; Sesana et al., 2021). Given its age, current condition, and location within a seismically

active and climatically sensitive area, the Temple of Apollo exhibits a high degree of long-term vulnerability.

4.1 Material Vulnerability of the Temple of Apollo

The vulnerability of the materials of the Temple of Apollo constitutes a critical factor in understanding the monument's overall susceptibility, as its state of preservation is directly influenced by the inherent properties of its structural material and its long-term exposure to environmental stressors. As previously mentioned, the temple is constructed from local oolitic limestone, a porous carbonate rock that was likely selected due to its availability and relative ease of workmanship. However, its granular microstructure and porous nature make it particularly susceptible to moisture absorption, the transport of soluble salts, and the progressive weakening of its structural cohesion (Siegesmund & Snethlage, 2011). The visual assessment of the monument reveals extensive and spatially heterogeneous material deterioration resulting from the long-term action of multiple degradation mechanisms.

It should be noted that the deterioration patterns discussed below are based on visual and macroscopic observation and are described according to the terminology established in the *“ICOMOS-ISCS Illustrated Glossary on Stone Deterioration Patterns”* (ICOMOS-ISCS, 2008).

One of the most characteristic deterioration patterns observed is **granular disintegration**, where individual grains detach from the stone surface, leading to a gradual loss of cohesion. This phenomenon is particularly evident on the shafts of the columns, where rough, irregular surfaces and clear degradation of the original morphological finish can be observed.



Figure 15. Granular disintegration visible on a column.

Source: Author's photograph.

Furthermore, a substantial number of the columns exhibit evidence of **material loss**, manifested by the reduced morphological clarity of the flutings. This deterioration is accompanied by **edge rounding**, resulting in the blunting or near-complete disappearance of the original geometric features. These alterations affect not only the physical condition of the monument but also the visual integrity of its original architectural design.

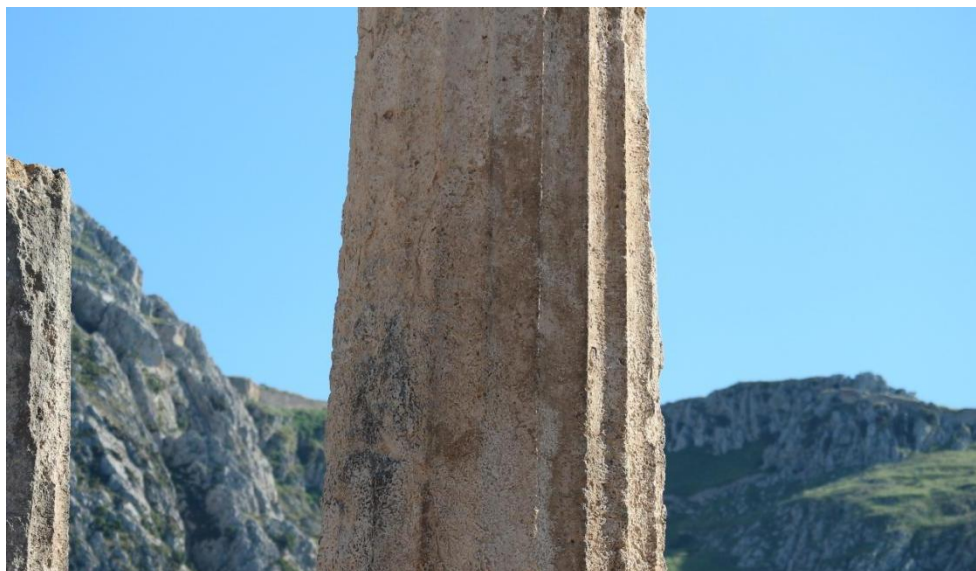


Figure 16. Material loss and edge rounding affecting the fluting of a column.

Source: Author's photograph.

A particularly pronounced form of deterioration is **alveolization**, characterized by the presence of extensive cavities on exposed column surfaces. This phenomenon

corresponds to progressive localized material loss through the development of interconnected cavities, indicating advanced disintegration of the porous stone.



Figure 17. Alveolization on an exposed column surface, showing the development of cavities associated with localized material loss.

Source: Author's photograph.

Localized **pitting** has been observed in specific areas, suggesting that weathering processes are progressing at different rates and stages of development within the same monument. This spatial variability may be related to airborne salt transport, as well as local micro-climatic conditions, material heterogeneity, and differential moisture exposure.

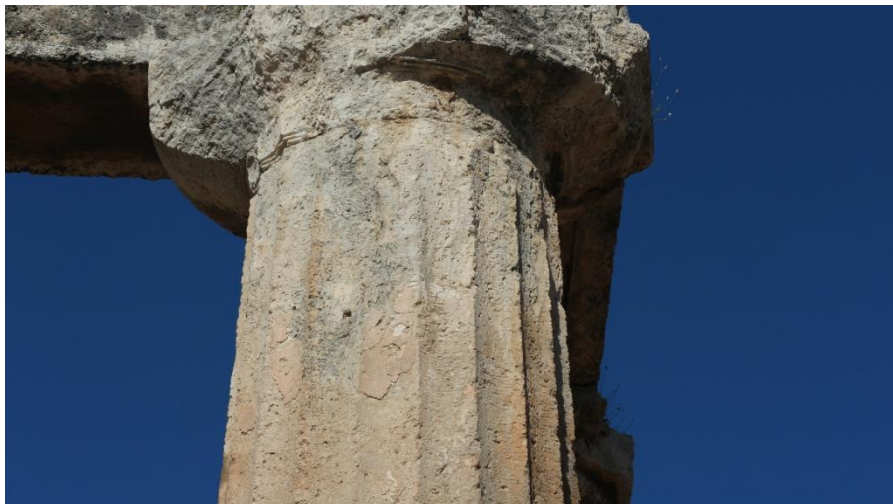


Figure 18. Localized pitting on the limestone surface, illustrating heterogeneous surface weathering.

Source: Author's photograph.

Another significant characteristic is **differential weathering**. Visual inspection reveals that deterioration is not uniformly distributed, either among different columns or across different surfaces of the same structural element. The preservation of the original surface morphology varies considerably, with some areas remaining relatively intact, while others exhibit severe material loss and advanced weathering. This spatial variability may be related to differences in orientation, solar exposure, wind-driven moisture, rainwater runoff, and airborne salt deposition.

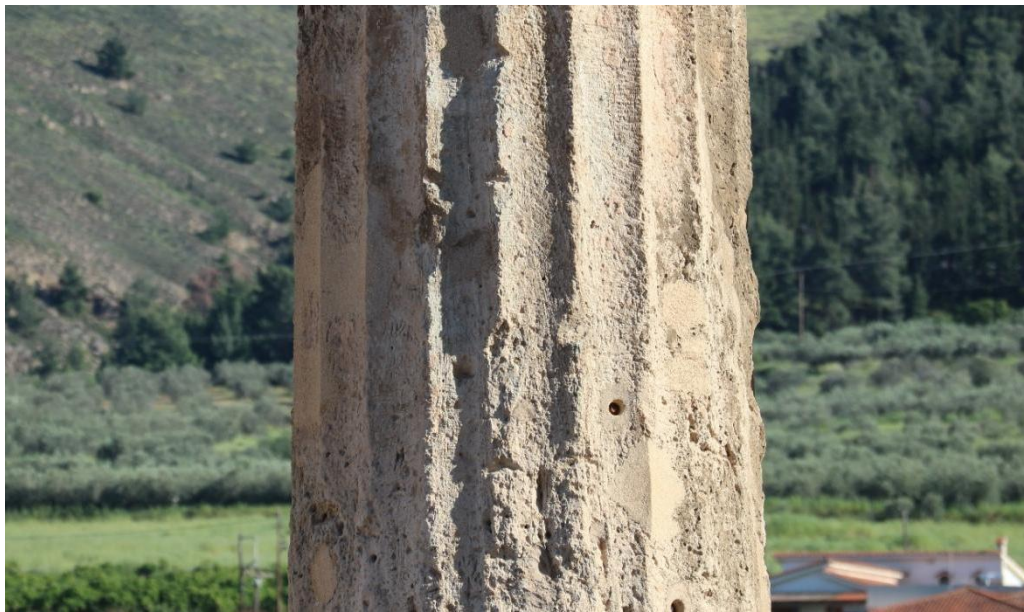


Figure 19. Differential weathering across the monument, showing variations in surface preservation and material loss.

Source: Author's photograph.

Localized **cracking** and **fracturing** are also evident, primarily in upper structural members and connection points. These discontinuities are of particular concern, as they provide pathways for the ingress of moisture and soluble salts into the stone matrix, thereby promoting and accelerating further deterioration processes.



Figure 20. Localized cracking and fracturing affecting an upper structural element.

Source: Author’s photograph.

Additionally, **surface deposits** and **soiling** were observed, primarily on sheltered or less exposed surfaces, together with localized water runoff traces. Although their exact composition cannot be confirmed without laboratory analysis, these surface alterations may affect the moisture transfer characteristics of the stone, potentially influencing subsequent deterioration processes.

Biological colonization was also observed, particularly in joints and horizontal surfaces where moisture is retained. It appears that biological growth is more pronounced in the peripheral remains of the temple. Such biological activity may further contribute to material deterioration through mechanical pressure and localized chemical alteration.



Figure 21. Biological colonization on the stone surface, particularly within joints and moisture-retaining areas.

Source: Author’s photograph.

An additional vulnerability factor is **the presence of previous conservation or stabilization interventions**, visually identifiable through differences in material appearance and surface behavior compared to the original stone. Potential incompatibilities between the original limestone and later repair materials, such as cement mortars or metallic reinforcements, may contribute to localized deterioration due to differences in porosity, moisture permeability, and thermal behavior. Metallic reinforcements may also have contributed to localized discoloration through the formation of corrosion products.

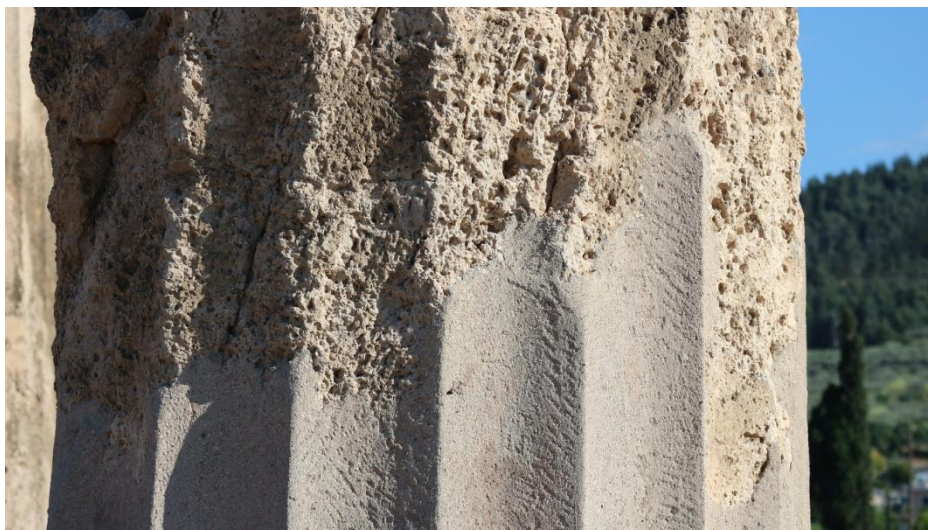


Figure 22. Previous intervention using cement-based mortar in contact with the original limestone.

Source: Author's photograph.

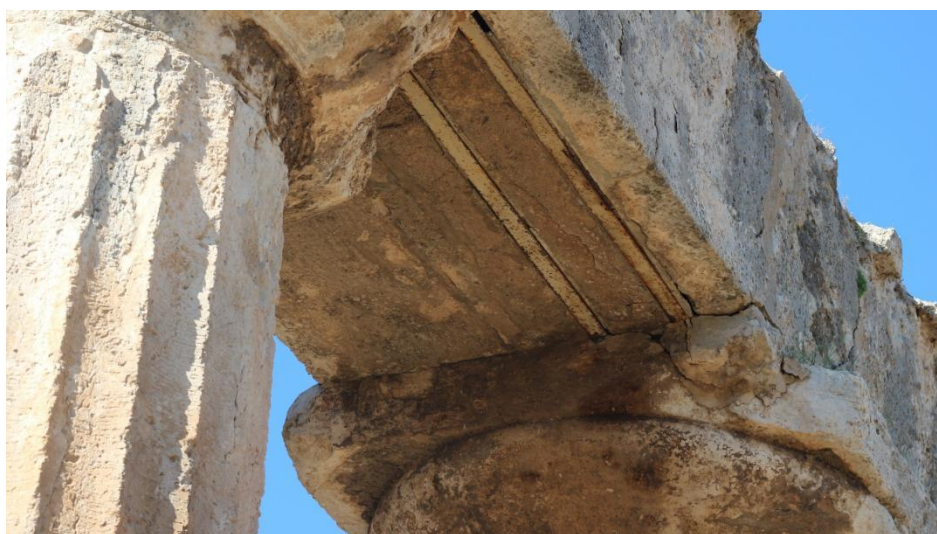


Figure 23. Metallic reinforcement associated with a previous stabilization intervention, with localized discoloration visible around the intervention area.

Source: Author's photograph.

Concurrently, the calcareous composition of the stone renders it inherently susceptible to **chemical weathering processes**. Atmospheric pollutants such as sulfur dioxide (SO₂), even at relatively low concentrations, can react with calcium carbonate, contributing to surface weakening and progressive material degradation.

The Temple of Apollo exhibits a complex and multifaceted pattern of material degradation, characterized by granular disintegration, material loss, alveolization, differential weathering, cracking, surface alterations, biological colonization, and potential incompatibilities associated with prior interventions. Consequently, the material vulnerability of the monument can be regarded as high.

4.2 Structural Sensitivity and Mechanical Behaviour

The structural vulnerability of the Temple of Apollo in Ancient Corinth is associated with the inherent characteristics of its original construction, as well as with the long-term effects of deterioration, environmental stresses, and later interventions. The monument's limestone construction is characterized by high compressive strength, but it demonstrates limited tensile resistance and brittle behavior under asymmetrical or dynamic loading conditions. These characteristics are commonly observed in historic stone structures (Feilden, 2003).

The mechanical behavior of such monuments depends not only on material strength, but also on the geometric stability of the structural system, the interaction between structural members, and the condition of load-transfer contact surfaces. In the Temple of Apollo, long-term weathering may compromise this behavior, as material loss, surface deterioration, and local discontinuities can reduce load-transfer efficiency and result in localized stress redistribution.

The visual assessment of the monument indicates that its structural behavior is not entirely uniform. Of particular note is the side with the three columns, which appears to exhibit an outward inclination from the vertical alignment (Figure 24). In historic stone structures, such geometric deviations may be associated with load redistribution, local displacements, or long-term variations in support conditions. The presence of local cracks, discontinuities, and irregularities between structural members further suggests increased structural vulnerability. Even limited discontinuities can significantly affect mechanical behavior, as stability depends on the interaction between individual elements and the

continuous transfer of compressive loads through contact. In addition, cracks or openings at connection points may act as stress concentration zones and contribute to local instability.



Figure 24. Apparent outward inclination of the columns on the three-column side of the Temple of Apollo.

Source: Author's photograph.

The presence of mortars and metal elements resulting from prior restoration or stabilization interventions is also of significance. While it is plausible that these materials were incorporated to enhance the monument's structural performance, their long-term compatibility with the original structural system remains uncertain. Differences in stiffness and mechanical behavior between the original stone and later materials, particularly metal elements, may influence load redistribution and the overall structural response of the monument.

Seismic exposure constitutes an additional critical factor, given the high seismicity of the Corinth region. Ancient stone monuments are inherently vulnerable to horizontal dynamic loading due to the brittle nature of the material, low tensile strength, and their reliance on geometric stability and interaction between discrete structural members. In the case of the Temple of Apollo, this vulnerability may be further increased by its fragmentary state of preservation, as the surviving structure no longer functions as a complete structural system. The remaining stone columns supporting the heavy horizontal elements are therefore potentially susceptible to relative displacement, local instability, or

partial overturning under strong seismic excitation, particularly in the presence of material deterioration and discontinuities.

The Temple of Apollo therefore presents a significant degree of structural vulnerability, resulting from the combined effects of the inherent mechanical limitations of its stone structural system, long-term material deterioration, and the high seismic exposure of the region. These conditions necessitate a case-specific evaluation by specialized professionals.

4.3 Site and Environmental Exposure

The exposure of the Temple of Apollo is shaped by three main factors: its geographical location, environmental conditions, and human activity. The monument is situated within an open archaeological site under a Mediterranean climate, where seasonal and daily fluctuations in temperature and humidity contribute to the gradual deterioration of its materials.

The monument's open and unprotected setting increases its exposure to environmental stressors such as solar radiation, wind, and precipitation. The surrounding terrain, lacking substantial natural or protective barriers, facilitates wind exposure and the deposition of dust, pollutants, and airborne particles onto the monument's surfaces. In addition, the monument's proximity to the Gulf of Corinth may increase exposure to marine salts, while air pollution from urban and industrial activities in the wider Corinth area may further contribute to environmental degradation.

Human activity represents an additional and significant exposure factor. As part of a prominent archaeological site, the monument is exposed to considerable visitor activity throughout the year. Continuous visitor presence increases the likelihood of accidental contact, surface wear, and localized mechanical stress, particularly in vulnerable areas. The close proximity of parking facilities, together with regular tourist transportation including buses and private vehicles, may further increase environmental pressure through emissions, dust, noise, and localized vibrations in the surrounding area. The infrastructure required to support tourism and site accessibility also places anthropogenic pressure on the monument's immediate surroundings. Although tourism contributes to the cultural and economic significance of the site, it also represents a continuous source of anthropogenic stress that should be considered in conservation planning.

5 Integrated Hazard and Risk Assessment

5.1 Risk Assessment Framework

5.1.1 Risk Framework

Risk theory provides a conceptual and analytical foundation for identifying, evaluating, and managing potential threats and their consequences. It supports decision-making under uncertainty by offering tools to anticipate adverse events, reduce vulnerabilities, and strengthen resilience in complex socio-environmental systems. In addition to technical assessment, risk theory incorporates governance and ethical dimensions related to prevention, preparedness, and adaptive responses to uncertain future conditions (Roeser et al., 2012). Within the context of cultural heritage conservation, these principles are particularly relevant for assessing the susceptibility of the Temple of Apollo at Ancient Corinth to multiple hazards associated with climate change and seismic activity.

In disaster risk studies, risk is generally understood as the probability of harmful consequences resulting from the interaction between hazardous events and vulnerable systems (Roeser et al., 2012). According to the United Nations Office for Disaster Risk Reduction (UNDRR, 2017), “*disaster risk*” refers to the potential for loss of life, physical damage, social disruption, or degradation of assets occurring within a defined period and influenced by hazard, exposure, vulnerability, and coping capacity. This approach emphasizes that disasters do not result solely from the occurrence of hazards, but emerge from the interaction between environmental threats and the conditions of exposed and vulnerable systems (UNDRR, 2015). Thus, “*disaster risk*” is commonly represented through the following relationship:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \times \text{Exposure} \quad (5.1)$$

This formulation demonstrates that risk increases when hazards intensify, exposure expands, or vulnerability remains high. Conversely, risk may be mitigated through a variety of measures, including improved adaptive capacity and resilience-building interventions. This conceptualization underpins the Sendai Framework for Disaster Risk Reduction (UNDRR, 2015) and climate risk frameworks developed by the IPCC (2022),

wherein risk is similarly conceptualized through the interaction of hazard, exposure, and vulnerability.

The three principal components of risk are defined as follows:

Hazard – A hazard can be understood as a physical event, process, or phenomenon with the potential to generate harmful consequences for people, infrastructure, or cultural heritage assets. Such events may trigger damage, disruption, or loss depending on their intensity and the conditions of the exposed system (UNDRR, 2017).

Vulnerability – Vulnerability describes the set of physical, social, economic, and environmental conditions that influence how susceptible individuals, communities, assets, or systems are to the effects of hazards. It reflects the extent to which these conditions may increase the likelihood of damage and reduce the ability to withstand or recover from adverse impacts (UNDRR, 2017).

Exposure – Exposure refers to the presence and distribution of people, infrastructure, housing, productive resources, and other assets situated in areas where hazardous events may occur. It relates to the extent to which these elements are positioned in locations that may be affected by potential threats (UNDRR, 2017).

Contemporary approaches to cultural heritage risk emphasize that hazards should not be assessed in isolation, but in relation to vulnerability and exposure conditions. This viewpoint is particularly relevant for the Temple of Apollo at Ancient Corinth, where risk is influenced not only by external threats but also by the monument's current state of preservation and its ability to withstand adverse impacts. Accordingly, risk assessment combines hazard analysis, vulnerability evaluation, and resilience-oriented planning to support long-term conservation under changing environmental conditions (IPCC, 2022). This approach also provides the basis for considering interacting hazards within a broader multi-hazard framework.

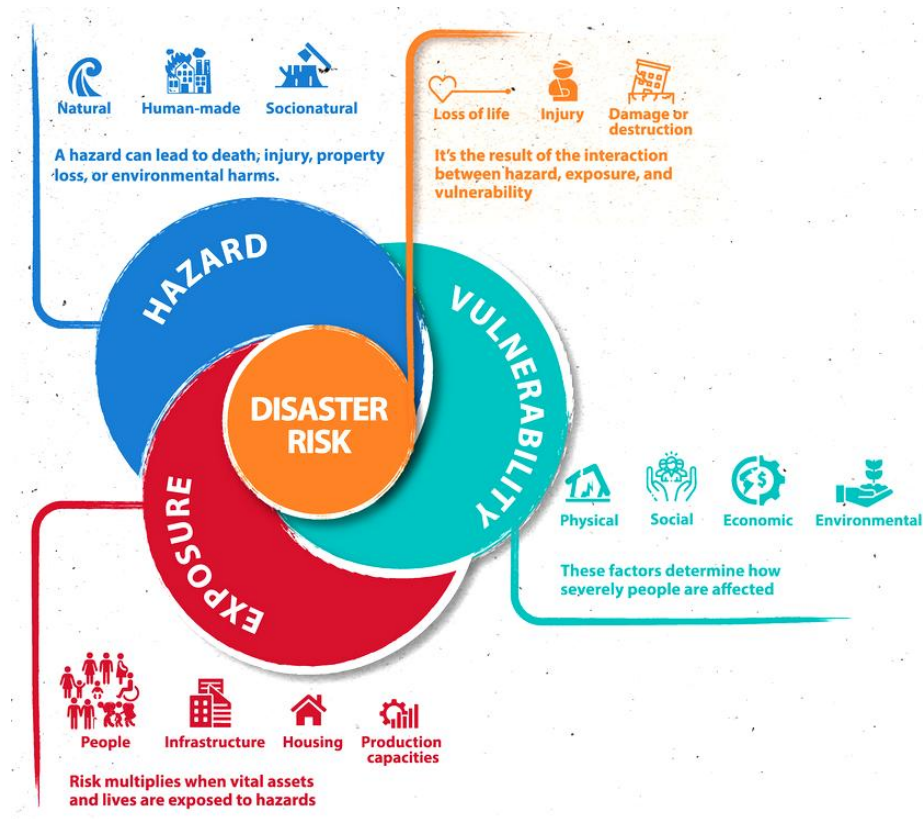


Figure 25. Disaster Risk.

Source: UNDRR, (2015).

5.1.2 Compound Hazards

Compound hazards refer to the interaction of two or more hazards occurring simultaneously, sequentially, or through cascading processes, generating impacts that may exceed those produced by each hazard independently (IPCC, 2022). This concept recognizes that risk may result from interconnected processes whose combined effects can amplify damage and increase vulnerability.

In cultural heritage contexts, a compound hazard approach is particularly relevant, as monuments are often exposed to multiple stressors operating across different temporal scales. At the Temple of Apollo at Ancient Corinth, compound hazards may arise through various mechanisms involving earthquakes in combination with climate-related stressors. These interactions may include the following:

Seismic activity and material deterioration: Long-term deterioration caused by weathering processes, natural cracking, and stone decay may weaken structural elements, increasing vulnerability during seismic events.

Heavy rainfall and seismic instability: Intense rainfall may contribute to soil erosion or localized instability around the monument, potentially amplifying the effects of seismic ground motion.

Thermal stress and humidity cycling: Repeated expansion and contraction due to temperature fluctuations, combined with moisture ingress, may accelerate deterioration and reduce the monument's resistance to additional hazards.

Cascading hazard effects: An earthquake may trigger secondary impacts such as structural displacement, falling debris, or increased susceptibility to future environmental degradation.

These interactions demonstrate that risk assessment cannot be based simply on the addition of independent hazards. Compound hazards may generate non-linear impacts, where combined consequences exceed those associated with individual hazards considered separately (Kappes et al., 2012; IPCC, 2022). A compound hazard approach therefore provides a more realistic understanding of multi-hazard processes and forms the basis for the risk assessment methodology applied in this study.

5.2 Risk Analysis Methodology and Input Data

The potential impacts of climate change on the Temple of Apollo at Ancient Corinth are evaluated through a risk assessment methodology designed to examine the monument's vulnerability under projected future conditions. The analysis is based on the methodology proposed by Kapsomenakis et al. (2022) and implemented through the “*DEAR-Clima*” tool.

“*DEAR-Clima*”, a specialized computational application for climate-related risk analysis, is used to process climate and geological data and generate quantitative assessments of the threats facing the monument. The geographical coordinates of the Temple of Apollo at Ancient Corinth (37.90597° N, 22.87904° E) are utilized as the input parameters for the implementation of the analysis (Latitude and Longitude Finder on Map Get Coordinates, n.d.).

The methodological approach involves a systematic process consisting of hazard characterization, vulnerability and exposure assessment, hazard quantification, and overall

risk integration. This comprehensive approach enables a systematic evaluation of both climatic and seismic hazards affecting the monument.

Future climate conditions are examined under two “*Representative Concentration Pathways*” (RCP4.5 and RCP8.5), representing moderate and high greenhouse gas emission scenarios, respectively. These scenarios provide projections of future changes in temperature, precipitation, and aridity over different time horizons and form the basis for evaluating the evolution of hazard conditions. Hazard conditions are compared between the reference period (1971-2000) and future periods (2021-2030, 2041-2050, and 2091-2100), allowing for the assessment of temporal changes in risk patterns.

Hazard intensity is assessed using a set of selected indicators commonly applied in climate impact and risk assessment studies, including:

- **TX₃₇**: Annual number of days with temperatures exceeding 37°C, representing extreme heat conditions.
- **TN₀**: Annual number of frost days (temperature below 0°C), indicating freeze-related stress.
- **PR₉₉**: Frequency of extreme precipitation events.
- **FWI₄₅**: Fire Weather Index threshold indicator (FWI > 45), representing high to extreme wildfire hazard conditions.
- **SLR**: Sea Level Rise indicator, used to characterize coastal flood and inundation hazard intensity.
- **AI (Aridity Index)**: Indicator expressing the relationship between precipitation and evapotranspiration.
- **PGA (Peak Ground Acceleration)**: Indicator used to characterize seismic hazard intensity.

These indicators enable a semi-quantitative evaluation of environmental pressures and provide a consistent framework for comparing hazard intensity under different climate scenarios. The selection of these indicators is informed by their extensive utilization in

climate vulnerability assessments and their pertinence in examining deterioration processes in stone-built cultural heritage structures (Kapsomenakis et al., 2022).

Risk assessment is further supported through the application of the **CCTHaz** index (Combined Climate Threat Hazard index), which evaluates climate-related hazards, and the **HHI** index (Heritage Hazard Index), which integrates both climatic and seismic threats into a combined hazard assessment. These composite indices synthesize the selected hazard indicators and support the estimation of overall hazard conditions affecting the monument under current and future scenarios (Kapsomenakis et al., 2022).

Risk levels are interpreted according to the five-class hazard classification proposed by Kapsomenakis et al. (2022), ranging from “*No Hazard (N) to Low (L), Moderate (M), High (H), and Extreme Hazard (X)*”. This classification facilitates the interpretation and comparison of projected hazard conditions across time periods and emission scenarios. The quantified hazard indicators provide the basis for the integrated hazard and risk assessment presented in the following sections.

5.3 Hazard Characterization

Selected hazard indicators represent the principal climatic and geophysical stressors affecting the monument, acting both directly through material deterioration and structural stress, and indirectly through processes that increase long-term vulnerability.

Extreme Heat: Increasing temperatures and more frequent heatwaves contribute to thermal stress in stone materials, leading to repeated expansion and contraction cycles. These processes can result in micro-cracking, material fatigue, and progressive surface deterioration (Sesana et al., 2021; IPCC, 2021). For the monument at Ancient Corinth, prolonged exposure of weathered stone surfaces may intensify these effects and increase susceptibility to material degradation.

Frost: Freeze–thaw cycles may occur when water infiltrates porous stone materials and subsequently freezes. The expansion of water during freezing generates internal stress, leading to cracking, scaling and gradual material loss (Grossi et al., 2007; Sesana et al., 2021). Existing fractures and porous zones may increase sensitivity to freeze-related deterioration.

Heavy Precipitation: Intense rainfall events increase moisture infiltration into stone, promoting salt mobilization, chemical weathering and biological colonization, which can accelerate deterioration processes (Sesana et al., 2021). For exposed archaeological remains, these effects may be amplified through runoff concentration and prolonged moisture retention.

Wildfires: Fires can affect stone monuments both directly and indirectly. Exposure to high temperatures may induce thermal shock, cracking, and surface spalling, while post-fire loss of vegetation can increase soil erosion, runoff, and sediment transport around the monument, potentially affecting its stability (Sesana et al., 2021). However, wildfire hazard is not considered a significant threat for the monument at Ancient Corinth, based on current site conditions and exposure characteristics, and is therefore screened out from subsequent vulnerability analysis.

Sea Level Rise: Sea level rise may increase coastal flooding, saltwater intrusion, and marine aerosol exposure, intensifying salt crystallization and moisture-related deterioration in exposed stone structures (IPCC, 2021; Sesana et al., 2021). However, due to the inland location and limited direct exposure of the monument to coastal processes, sea level rise is not considered a significant threat under current conditions and is therefore screened out from subsequent vulnerability analysis.

Aridity: Prolonged drought conditions may contribute to salt accumulation on stone surfaces, increased thermal stress, and potential soil shrinkage affecting foundation stability (Nastos et al., 2013; Kapsomenakis et al., 2022).

Seismic Activity: The Corinth region is characterized by high seismicity due to active tectonic processes, and earthquakes represent a major hazard capable of causing structural damage, displacement of stone elements and potential collapse. Peak Ground Acceleration (PGA) is used to characterize seismic hazard intensity, based on the seismic hazard zonation proposed for Greece in the context of the ongoing revision of Greek regulatory frameworks, including EAK2000 and the European EuroCode-8 standards (Pitilakis et al., 2024). For the monument at Ancient Corinth, seismic activity constitutes a dominant hazard due to the tectonic setting of the region, while the structural sensitivity of archaeological remains increases their vulnerability to seismic impacts.

Air pollution: Air pollution is a significant stressor affecting stone materials through chemical and physical processes. Pollutants such as particulate matter (PM₁₀, PM_{2.5}), sulfur dioxide (SO₂), nitrogen oxides (NO_x), and ozone (O₃) contribute to the deterioration of carbonate stones like limestone. Particulate matter deposits on surfaces, promoting soiling and moisture retention, while SO₂ and NO_x form acidic compounds that react with calcium carbonate, leading to gypsum formation and material loss (Vallero, 2014; Skoulikidēs, 2000). Ozone acts as a strong oxidizing agent, enhancing atmospheric reactions and indirectly accelerating degradation. For the monument at Ancient Corinth, continuous exposure to these pollutants may result in surface discoloration, crust formation, and gradual material deterioration.

5.4 Hazard Quantification and Index Results

The quantification of environmental hazards is based on climate and seismic indicators representing measurable hazard intensity. Quantified indicator results for each hazard sub-index are presented below under the two climate scenarios (RCP4.5 and RCP8.5).

5.4.1 Individual Hazard Indicators

Extreme Heat

2021-2030	Relative Change in TX ₃₇ (%)	Value of EHHaz	Qualitative characterization of EHHaz
RCP 4.5	72.65	3	H
RCP 8.5	72.65	3	H
2041-2050			
RCP 4.5	122.54	4	X
RCP 8.5	186.21	4	X
2091-2100			
RCP 4.5	157.99	4	X
RCP 8.5	462.58	4	X
No Hazard (N) to Low (L), Moderate (M), High (H), and Extreme Hazard (X)			

Table 2. Extreme hot days for RCP 4.5 and 8.5 (TX₃₇)

Results for TX₃₇ indicate a substantial increase in extreme hot days under both emission scenarios, with the highest intensification projected under RCP8.5 for 2091-2100. This trend confirms increasing thermal stress as a dominant climate-related hazard for the monument.

Frost

2021-2030	Relative Change in TN_0 (%)	Value of FHaz	Qualitative characterization of FHaz
RCP 4.5	-45.84	0	N
RCP 8.5	5.73	0	N
2041-2050			
RCP 4.5	-47.56	0	N
RCP 8.5	-30.37	0	N
2091-2100			
RCP 4.5	-55.30	0	N
RCP 8.5	-96.56	0	N
No Hazard (N) to Low (L), Moderate (M), High (H), and Extreme Hazard (X)			

Table 3. Frost days for RCP 4.5 and 8.5 (TN_0)

The results for TN_0 indicate notable relative changes in the number of frost days across the future periods under both the RCP4.5 and RCP8.5 scenarios. In most cases, a substantial decrease in the number of frost days is projected. The largest reduction is observed under RCP8.5 during 2091–2100, reaching -96.56%, while a slight increase of 5.73% is projected under RCP8.5 during 2021–2030. According to the adopted hazard assessment methodology, however, all changes result in an FHaz value of 0 and are therefore classified as No Hazard (N) across all time horizons and emission scenarios. The projected decrease in frost days suggests a lower potential for frost-related damage, although other climate-related hazards may become more pronounced in the future.

Heavy Precipitation

2021-2030	Relative Change in PR_{99} (%)	Value of EPHaz	Qualitative characterization of EPHaz
RCP 4.5	-16.66	0	N
RCP 8.5	16.66	1	L
2041-2050			
RCP 4.5	0	0	N
RCP 8.5	-16.66	0	N
2091-2100			
RCP 4.5	-16.66	0	N
RCP 8.5	-33.33	0	N
No Hazard (N) to Low (L), Moderate (M), High (H), and Extreme Hazard (X)			

Table 4. Days per decade with extreme precipitation (PR_{99})

Results for PR₉₉ indicate limited changes in extreme precipitation, with hazard levels remaining predominantly low or absent. This suggests a comparatively minor contribution of precipitation extremes to overall hazard conditions.

Aridity

2021-2030	Value of AI	Value of AHaz	Qualitative characterization of AHaz
RCP 4.5	0.125	4	X
RCP 8.5	0.163	4	X
2041-2050			
RCP 4.5	0.130	4	X
RCP 8.5	0.100	4	X
2091-2100			
RCP 4.5	0.085	4	X
RCP 8.5	0.072	4	X
No Hazard (N) to Low (L), Moderate (M), High (H), and Extreme Hazard (X)			

Table 5. Results of AI hazard assessment

Results for the aridity indicator show persistently low AI values across all scenarios, corresponding to extreme aridity hazard conditions. Although AI decreases across future periods, all projected values remain within the arid threshold range, resulting in a consistently extreme AHaz classification.

Seismicity

Seismic hazard (SHaz) is assessed using Peak Ground Acceleration (PGA), calculated in accordance with EAK2000 and EuroCode 8. For the study area, the reference ground acceleration is taken as $ag_R=0.24g$, in accordance with the seismic zonation of Greece.

The foundation conditions of the Temple of Apollo are classified as Ground Category B, based on interpretation of the regional geological map developed by Efthymios Lekkas and available through elekkas.gr (see Appendix C). Although the monument is founded on bedrock, the broader sedimentary and tectonically disturbed setting, together with the presence of active faulting, supports the adoption of Category B as a conservative and technically realistic assumption, corresponding to a soil factor of $S=1.2$. This classification accounts for potential variability in subsurface conditions and

possible local amplification effects. In addition, the local ground slope at the monument is estimated to be less than 15° , as the structure is situated on a relatively level platform. Therefore, the topographic amplification factor is taken as $S_T=1$. PGA is estimated as:

$$PGA \approx ag = \gamma_I \cdot a_{gR} \cdot S \cdot S_T = 1 \cdot 0.24 \cdot 1.2 \cdot 1 = 0.288 \text{ g}$$

	Value of PGA	Value of SHaz	Qualitative characterization of SHaz
PGA	0.288	3	H
No Hazard (N) to Low (L), Moderate (M), High (H), and Extreme Hazard (X)			

Table 6. Value of Seismic Activity

Thus, extreme heat and aridity emerge as the primary climate-related hazards, both reaching extreme hazard classification under future scenarios. Seismic hazard remains consistently high, while heavy precipitation remains comparatively limited. Frost also retains hazard significance, as substantial relative changes in TN0 correspond to moderate to extreme frost hazard classifications.

5.4.2 Excluded Hazard Indicators

Sea Level Rise

The Temple of Apollo is located inland, at a considerable distance from the coastline. Although the broader Corinth area is influenced by coastal processes, the monument itself lies more than several kilometers from the sea and at an elevation that significantly reduces its exposure to marine flooding. As a result, it does not satisfy the conditions required for inclusion in the **Coastal Flooding Hazard Sub-Index**, and the **CFHaz** value can therefore be considered negligible (set to zero).

Wildfires

The Temple of Apollo is situated within an archaeological site characterized by limited dense vegetation in its immediate surroundings. This reduces the likelihood of wildfire spread directly affecting the monument. Consequently, the site does not fulfill the criteria for the **Wildfire Hazard Sub-Index**, and the **FWI₄₅** index can be assumed to be zero.

Air Pollution

Air pollution is not included in the hazard assessment according to the methodology of Kapsomenakis et al. (2022), and is therefore excluded from the calculation of the HHI. However, it represents an important environmental factor contributing to the deterioration of carbonate stone materials. Pollutants such as PM₁₀, PM_{2.5}, SO₂, NO_x, and O₃ promote surface degradation through deposition and chemical reactions, leading to discoloration, crust formation, and material loss.

The following figures illustrate the temporal variation of key atmospheric pollutants (NO₂, O₃, SO₂, PM₁₀, and PM_{2.5}) and the Air Quality Index (AQI) in the study area, based on Copernicus data.

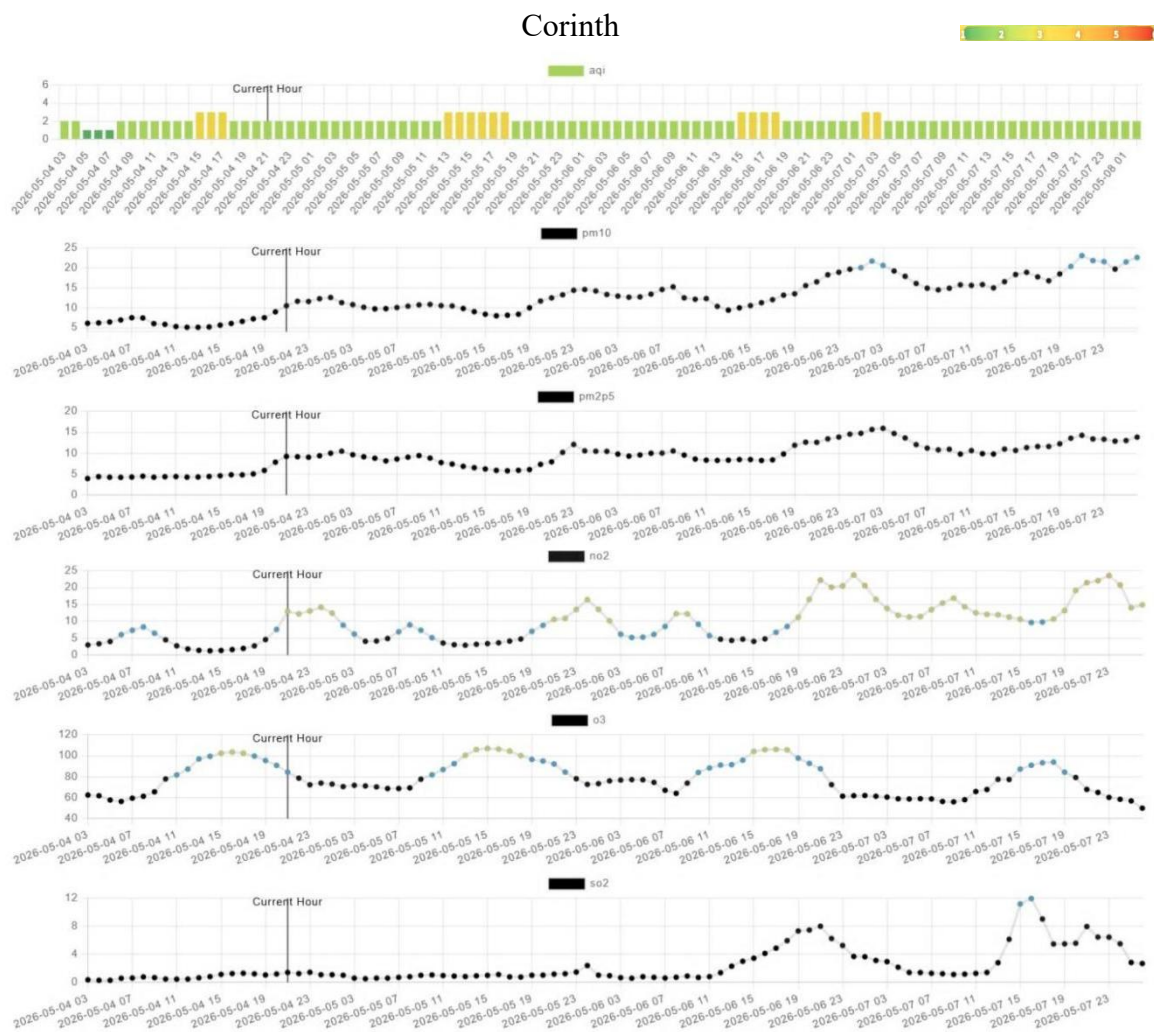


Figure 26. Temporal variation of key atmospheric pollutants (NO₂, O₃, SO₂, PM₁₀, and PM_{2.5}) and the Air Quality Index (AQI) in the study area, based on Copernicus data.

Source: Copernicus, (2026).

The data indicate moderate but persistent pollution levels, with noticeable temporal variability. Ozone (O₃) shows clear diurnal variation, reflecting photochemical activity, while particulate matter (PM₁₀ and PM_{2.5}) remains consistently present, indicating continuous deposition potential. Sulfur dioxide (SO₂) exhibits short-term peaks relevant to chemical weathering processes, and nitrogen dioxide (NO₂) reflects ongoing anthropogenic emissions. Although AQI values remain within low to moderate levels, continuous exposure may contribute to long-term material deterioration.

5.4.3 Combined Climate Threat Hazard (CCTHaz)

The Combined Climate Threat Hazard (CCTHaz) represents the aggregate climate-related hazard level derived from the summation of individual hazard sub-indices. It provides an integrated measure of cumulative climate stress affecting the monument and serves as input for the Heritage Hazard Index (HHI). The Combined Climate Threat Hazard Index (CCTHaz) is calculated using the following formula:

$$\text{CCTHaz} = \text{EHHaz} + \text{FHaz} + \text{EPHaz} + \text{AHaz} + \text{CFHaz} + \text{FWI}_{45} \quad (5.2)$$

RCP 4.5							
	TX ₃₇	TN ₀	PR ₉₉	AI	SLR	FWI ₄₅	CCTHaz
2021-2030	3	0	0	4	0	0	7
2041-2050	4	0	0	4	0	0	8
2091-2100	4	0	0	4	0	0	8

Table 7. Estimation of CCTHaz for RCP4.5

RCP 8.5							
	TX ₃₇	TN ₀	PR ₉₉	AI	SLR	FWI ₄₅	CCTHaz
2021-2030	3	0	1	4	0	0	8
2041-2050	4	0	0	4	0	0	8
2091-2100	4	0	0	4	0	0	8

Table 8. Estimation of CCTHaz for RCP8.5

CCTHaz results indicate elevated combined climate hazard conditions across both emission scenarios, driven primarily by the contribution of extreme heat and persistent aridity. Higher CCTHaz values under RCP8.5, particularly for 2021-2030, reflect stronger

cumulative climate stress, while later reductions are associated with the signed contribution of declining frost hazard within the index calculation.

5.5 Integrated Hazard Assessment

5.5.1 Heritage Hazard Index (HHI)

The Combined Climate Threat Hazard (CCTHaz), as derived in the previous section through the aggregation of individual climate hazard sub-indices, is employed in the present stage as the climate-related input for the computation of the Heritage Hazard Index (HHI). As a composite indicator representing the cumulative impact of multiple climatic stressors on the monument, CCTHaz is integrated with the seismic hazard (SHaz) component to assess the overall multi-hazard conditions affecting the heritage asset. This combined approach enables the evaluation of the potential severity arising from the interaction of climate-related and seismic threats. Accordingly, the Heritage Hazard Index (HHI) is calculated using the following equation:

$$HHI = CCTHaz + \sqrt{(CCTHaz) \times (SHaz)} \quad (5.3)$$

RCP 4.5									
	TX ₃₇	TN ₀	PR ₉₉	AI	SLR	FWI ₄₅	SHaz	CCTHaz	HHI
2021-2030	3	0	0	4	0	0	3	7	11.58
2041-2050	4	0	0	4	0	0	3	8	12.90
2091-2100	4	0	0	4	0	0	3	8	12.90

Table 9. Estimation of the HHI for RCP 4.5

RCP 8.5									
	TX ₃₇	TN ₀	PR ₉₉	AI	SLR	FWI ₄₅	SHaz	CCTHaz	HHI
2021-2030	3	0	1	4	0	0	3	8	12.90
2041-2050	4	0	0	4	0	0	3	8	12.90
2091-2100	4	0	0	4	0	0	3	8	12.90

Table 10. Estimation of the HHI for RCP 8.5

5.6 Risk Integration and Prioritization

After identifying and assessing individual hazards, and based on hazard indicators and HHI results, risks for the Temple of Apollo in Ancient Corinth can be integrated and prioritized, establishing a structured hierarchy of intervention priorities. Risk integration assesses hazard intensity in relation to vulnerability, exposure, and potential consequences in order to identify the principal risks affecting the monument. Risk prioritization, in turn, evaluates the relative severity of impacts and the likelihood of occurrence for each individual risk driver.

This integrated approach recognizes that risks should not be interpreted solely as isolated events, but also as interconnected processes capable of amplifying one another over time. In accordance with established principles of multi-hazard risk assessment (Kappes et al., 2012; Kapsomenakis et al., 2022; IPCC, 2022), a qualitative risk matrix is applied based on three criteria:

- **Severity**, representing the potential impact of a hazard on structural stability and material integrity;
- **Likelihood**, reflecting the probability or persistence of occurrence, informed by hazard indicators and composite indices;
- **Priority level**, indicating the urgency for conservation action based on the combined consideration of severity and likelihood.

Risk Prioritization Matrix 				
Risk Factor	Category	Severity	Likelihood	Priority Level
Seismic activity	 Geophysical ▾	 Extreme ▾	 High ▾	 Extreme
Extreme Heat	 Climatic ▾	 Extreme ▾	 High ▾	 Extreme
Aridity	 Climatic ▾	 High ▾	 High ▾	 High
Heavy Precipitation	 Climatic ▾	 Medium ▾	 Low ▾	 Low
Frost-related Deterioration	 Climatic ▾	 Low ▾	 Low ▾	 Low

Legend:

-  **Extreme** = Requires immediate conservation attention and priority intervention.
-  **High** = Requires immediate intervention and systematic monitoring.
-  **Medium** = Should be addressed through preventive management and regular monitoring.
-  **Low** = Requires periodic review and incorporation into routine site management.

Table 11. Risk prioritization matrix.

The risk prioritization matrix identifies seismic activity and extreme heat as the most critical threats affecting the monument. Seismic activity poses the most significant structural risk due to the tectonic context and the vulnerability of the surviving architectural remains to lateral forces. In addition, extreme heat represents an equally critical climatic stressor, accelerating thermal cracking, material fatigue, and surface deterioration. Aridity constitutes a high-priority risk due to its cumulative effects on material integrity and soil behavior. Heavy precipitation is assessed as a low-priority hazard due to its relatively limited frequency and impact. Frost-related deterioration is assigned the lowest priority because climatic analysis indicates the absence of frost days within the study area during the reference period, suggesting that freeze-thaw weathering is currently not an active deterioration mechanism for the monument.

Risk is further influenced by the monument's material and structural vulnerability, including the sensitivity of porous oolitic limestone to thermal stress, moisture imbalance, and salt crystallization, as well as weathered joints and the absence of reinforcement. Externally-driven exacerbating factors, including wind-driven erosion, airborne pollutants, traffic-related vibration, dust deposition, tourism, and broader urban pressures, have the potential to intensify deterioration processes. Despite the absence of these factors in the risk matrix, they are regarded as secondary stressors within the overarching risk interpretation framework.

Consequently, risk conditions should not be considered independently. Climatic stressors, particularly extreme heat and aridity, progressively reduce material cohesion and structural capacity, thereby increasing the monument's susceptibility to seismic loading. Lower-priority hazards, although individually less critical, may still contribute incrementally to long-term deterioration through interactions with other environmental and structural stressors. Thus, the matrix establishes priority levels, enabling targeted

intervention planning and aligning risk assessment with conservation management priorities.

6 Preservation and Adaptation Strategies

The vulnerability assessment of the Temple of Apollo identified multiple active and potential deterioration mechanisms, including granular disintegration, alveolar weathering, cracking, biological colonization, differential weathering, and the long-term effects of potentially incompatible past interventions. In parallel, the assessment of future climate scenarios (RCP 4.5 and RCP 8.5) indicated that changing environmental conditions may intensify existing deterioration processes, increasing the monument's long-term vulnerability. These findings reinforce the need to protect the Temple of Apollo as a unique and non-renewable cultural resource, with priority given to preserving its material integrity, archaeological value, and historical authenticity.

Effective conservation therefore requires an integrated and long-term approach capable of addressing both current deterioration mechanisms and emerging future risks. In line with contemporary conservation theory and the principles of the *“Venice Charter”*, conservation should be based on minimal intervention, respect for original materials, preventive monitoring, and systematic risk management (Muñoz Viñas, 2005; ICOMOS, 1964).

Within this context, this chapter presents targeted conservation and adaptation strategies for the Temple of Apollo, including measures to address material deterioration, structural stabilization, environmental monitoring, risk management, and periodic reassessment, with the aim of strengthening the monument's long-term resilience.

6.1 Conservation Measures

The conservation of archaeological monuments necessitates a scientifically documented approach, as its objective is to preserve the authentic material, limit deterioration, and ensure the long-term protection of the monument's historical and archaeological value. According to the principles of contemporary conservation theory, the concept of conservation encompasses not only direct interventions on the material itself, but also a broader strategy for the protection of cultural heritage (Muñoz Viñas, 2005). Furthermore, according to the theoretical principles that guided interventions on the

monuments of the Acropolis, as well as the Venice Charter, emphasis is placed on minimal intervention, the preservation of authenticity, and the avoidance of conjectural reconstructions (Bouras, 2007). These principles can be applied in the case of the Temple of Apollo, where the surviving structure constitutes primary historical evidence.

A key step in the planning of any conservation programme is to carry out a thorough and systematic documentation of the monument's current state of preservation. It is essential that conservation efforts are not based on fragmented observations or isolated interventions without a comprehensive understanding of deterioration mechanisms, material behaviour, and their interaction with the environment. The literature on archaeological site conservation recognizes documentation as a fundamental component for both diagnosis and future evaluation of interventions (de la Torre, 1997; Stanley-Price et al., 2003). In the case of the Temple of Apollo, where deterioration presents an uneven distribution, systematic mapping of deterioration phenomena, photographic documentation, comparative monitoring of pathological progression, and the use of standardized terminology such as that of ICOMOS-ISCS (2008) are required in order to ensure effective communication among the different scientific disciplines involved.

As a general rule, this documentation should be supported by targeted non-destructive or minimally invasive diagnostic analyses, where appropriate. This ensures that conservation decisions are based on objective data without compromising the integrity of the authentic material. Techniques such as portable X-ray fluorescence spectroscopy (portable XRF) and, where appropriate, X-ray diffraction (XRD) can contribute to the accurate characterization of materials and the identification of weathering products or salt residues. Concurrently, non-destructive methods such as infrared thermography, ultrasonic measurements, high-resolution digital photogrammetry, and three-dimensional laser scanning can provide critical data for detecting moisture, internal discontinuities, and for the overall assessment of the monument's state of preservation.

A critical issue for the conservation of the Temple of Apollo is moisture management, as the porous limestone material makes the monument especially susceptible to water penetration, the transport of dissolved salts, and the gradual weakening of the stone's internal cohesion (Siegesmund & Snethlage, 2011). The previous vulnerability assessment indicated that deterioration forms such as granular disintegration, alveolization, and differential surface weathering are likely associated with the presence of moisture and

repeated environmental stress. In this context, conservation measures should prioritize reducing the conditions that allow prolonged moisture retention or accumulation. This includes assessing rainwater drainage, identifying areas where water collects or becomes trapped, and examining whether previous interventions have disrupted the natural evaporation behavior of the original material.

As Charola (2000) noted, salt deterioration is a significant cause of decay in porous stone monuments. This phenomenon is closely linked to moisture. Salt crystallization within the stone's porous network creates repeated internal stresses, leading to gradual material loss, cavity formation, and surface erosion. Given the observed deterioration patterns in the Temple of Apollo, it is essential that any conservation strategy prioritizes addressing the underlying causes rather than merely the symptoms. As Price (1996) emphasizes, the use of inappropriate interventions without a full understanding of stone behavior may worsen the condition rather than mitigate it. Consequently, the treatment of salt deterioration should be based on scientifically documented investigations rather than on general corrective practices.

Another significant deterioration factor is biological weathering. The presence of biological growth on the monument's surfaces indicates local microenvironmental conditions that favor moisture retention and organism development. As noted by Caneva et al. (2008) and Warscheid and Braams (2000), biological organisms can accelerate deterioration through both mechanical and biochemical processes. It is important to note that root systems, surface expansion, and metabolically produced chemical compounds may further weaken the stone surface, which is already fragile. Therefore, the management of biological deterioration must be undertaken with particular care, using gentle and scientifically justified interventions while avoiding aggressive cleaning techniques that may cause additional material loss. In addition, it would be highly advantageous to conduct a thorough cleaning of the surrounding area, including the removal of vegetation, and of the Temple itself.

Particular importance must also be given to the compatibility of materials used in conservation interventions. Bouras (2007) emphasizes that intervention materials must be compatible both with the historic materials and with the structural behaviour of the monument. This principle is especially critical in the case of the Temple of Apollo, where there are indications of previous interventions of questionable compatibility. As noted by

Feilden (2003) and Siegesmund and Snethlage (2011), incompatible materials, such as dense cementitious mortars or metallic elements with different mechanical and thermal behavior, may act as accelerators of deterioration, causing moisture entrapment, internal stress development, or local chemical reactions. Therefore, before any intervention, careful assessment of existing additions and the evidence-based selection of compatible materials and techniques, following laboratory study, are required.

Finally, the conservation of the monument cannot be treated solely as a technical issue, but rather as a process of cultural management requiring interdisciplinary collaboration and ethically justified decision-making. Significant archaeological conservation programs, such as the one at the Acropolis, have shown that the success of interventions depends on collaboration between archaeologists, architects, engineers, conservators, and chemical engineers (Bouras, 2007). At the same time, such monuments constitute non-renewable cultural resources, making it essential that interventions be evidence-based, reversible where possible, and strictly justified (Stanley-Price et al., 2003).

6.2 Structural Stabilization Options

Potential structural stabilization options for the Temple of Apollo should be considered within the framework of a broader conservation and restoration strategy. This strategy should take into account the archaeological significance of the monument and the structural vulnerabilities identified through visual assessment. Given the monument's current state of complexity, any intervention should be preceded by a comprehensive technical study conducted by qualified specialists, including civil engineers, architects, and conservators, with the aim of developing a well-documented and integrated restoration program.

A primary priority is the detailed documentation of the monument's structural condition, in order to systematically record all observed geometric irregularities, cracks, discontinuities, and areas of material loss. This documentation should be combined with the conservators' assessment of the monument's state of preservation, allowing for a comprehensive evaluation of all forms of deterioration affecting the structure. Such a study should be completed prior to any intervention. Particular attention should also be given to the inclination of the temple, in order to determine whether it results from active structural instability or represents a long-term stabilized deformation. High-precision

geometric documentation, crack monitoring, and structural analysis could provide critical information for assessing structural safety and determining the necessity of intervention.

Potential stabilization measures may include the localized consolidation of weakened areas where cracks, discontinuities, or material loss appear to affect load transfer between structural elements. Given the monument's reliance on the interaction of individual stone members to maintain its stability, the restoration or improvement of structural continuity could contribute to its long-term safety and preservation. However, the selection of consolidation or strengthening materials must be made with particular care to ensure compatibility with the original limestone and to avoid introducing adverse mechanical or chemical effects.

As previously mentioned, the structural assessment should also include an evaluation of earlier restoration interventions in order to inform the development of an appropriate and sustainable conservation strategy. The metallic elements introduced during previous restoration attempts raise concerns regarding their compatibility with the original stone construction, both from structural and conservation perspectives. Subsequent to a thorough evaluation by specialists, a substantiated determination must be rendered concerning the extraction, substitution, or maintenance of these components to avert prospective deleterious repercussions on the monument's structural behavior or the conservation of its authentic material composition.

Given the high seismicity of the Corinthia region, it is essential that seismic vulnerability assessment be an integral part of the monument's structural evaluation and restoration planning. Historic stone monuments are particularly vulnerable to seismic forces due to their brittle mechanical behavior and reliance on the geometric stability of their structural components. In instances where deemed necessary, reversible strengthening measures compatible with conservation principles may be considered.

Therefore, structural stabilization options for the Temple of Apollo should remain highly case-specific and be developed only following a comprehensive structural and conservation assessment. Given the fragmentary condition of the monument and its significant cultural heritage value, any intervention should prioritize structural safety while minimizing alteration to the monument's authentic historic fabric.

6.3 Environmental Monitoring Measures

Environmental monitoring is a key part of the long-term strategy for the Temple of Apollo's preventive conservation, as environmental and structural factors directly impact both material deterioration and the monument's structural stability. As an open-air archaeological monument, the Temple is continuously exposed to a range of external factors which may impact its structural integrity, including temperature and humidity fluctuations, moisture infiltration, biological colonization, weather-driven deterioration processes and seismic activity (Sesana et al., 2021; ICOMOS, 2019).

A primary objective of monitoring should be the systematic assessment of microclimatic conditions, particularly temperature and relative humidity, as fluctuations in these parameters affect thermal stress, moisture migration, and salt crystallization processes within the porous calcareous stone fabric. As part of the current monitoring strategy, a fixed temperature and relative humidity data logger has already been installed on site, recording hourly micro-climatic fluctuations. Over time, the collected data may support the establishment of baseline environmental conditions and improve understanding of seasonal deterioration patterns.

Furthermore, it is imperative to systematically monitor biological colonization, particularly in joints, horizontal surfaces, and sheltered areas where moisture accumulation creates favourable conditions for biological growth. As stated in the research, biological activity may contribute to both mechanical and biochemical deterioration processes, further weakening vulnerable stone surfaces (Caneva et al., 2008; Warscheid & Braams, 2000). In addition, periodic monitoring of rainfall patterns, wind exposure, and airborne pollutants would provide useful information regarding weather-driven deterioration, moisture penetration, salt transport, and overall environmental exposure.

In addition, environmental stressors should be considered in relation to structural conservation, particularly given the existing outward inclination observed in the Temple structure and the high seismic risk identified through the risk assessment process. In instances where deemed necessary, structural monitoring devices such as crack monitoring devices, displacement sensors, tilt sensors, or accelerometers could be installed at vulnerable points to detect progressive movement and assess the monument's response to seismic events.

The monitoring framework could be further strengthened through integration with existing digital documentation resources. The three-dimensional digital model of the Temple of Apollo at Corinth, developed by James A. Herbst through the American School of Classical Studies at Athens, in conjunction with extant architectural survey drawings, provides a valuable baseline for comparative condition assessment, deterioration mapping, and future change detection. The integration of spatial documentation resources, such as GIS-based site plans or other archaeological mapping datasets, has the potential to further enrich this framework, where such resources are available. The incorporation of these resources could facilitate spatial analysis of environmental exposure, deterioration patterns, and long-term site management. The following section presents a summary of the proposed environmental monitoring measures for the Temple of Apollo, as outlined in Table 12.

Environmental / Structural Stressor	Suggested Monitoring Approach	Purpose	Frequency
Temperature & relative humidity fluctuations	Fixed data logger (already installed)	Monitoring thermal stress, moisture cycles, and environmental variability	Continuous (hourly)
Moisture infiltration	Visual inspection / moisture sensors where appropriate	Detection of persistent dampness and potential water penetration pathways	Periodic
Biological colonization	Visual inspection / photographic documentation	Monitoring biological deterioration in moisture-prone areas	Periodic
Structural instability	Crack monitoring, displacement, or tilt sensors where appropriate	Detection of progressive structural movement	Targeted
Seismic activity	Accelerometers where appropriate	Detection of progressive structural movement	Continuous / event-based
Long-term condition change	Comparison of 3D model, architectural drawings, and GIS documentation where available	Comparative condition assessment and deterioration mapping	Periodic

Table 12. Proposed environmental and structural monitoring strategy.

6.4 Management, Policy, and Governance Recommendations

The long-term preservation of the Temple of Apollo in Ancient Corinth depends not only on technical conservation interventions, but also on an effective management and governance framework capable of addressing environmental and social challenges. While structural stabilization, material conservation and environmental monitoring are fundamental components of protection, their efficacy is contingent on their integration into a comprehensive, long-term management strategy (ICOMOS, 2019; Muñoz Viñas, 2005).

An integrated management approach is therefore required, in which conservation activities, environmental monitoring, visitor management, and emergency preparedness operate in a coordinated manner. Climate change increases uncertainty and intensifies gradual environmental deterioration, making it necessary to move beyond reactive interventions toward a more preventive and adaptive management strategy, supported by regular risk assessments and structured maintenance protocols (Sesana et al., 2021; UNESCO, 2007).

Visitor management should also be considered a key aspect of long-term preservation, as the Temple of Apollo remains an important archaeological destination. Although visitor access enhances the cultural, educational, and social value of the site, it may also contribute to physical wear and indirect pressures associated with tourism activity. For this reason, balanced access planning, controlled circulation, and the protection of particularly vulnerable areas are necessary in order to maintain an appropriate balance between accessibility and conservation priorities.

Effective preservation also requires clear governance and coordination among the relevant authorities, including the Ministry of Culture, the Ephorate of Antiquities of Corinthia, the Directorate for the Restoration of Ancient Monuments, and, where relevant, the Ministry of Climate Crisis and Civil Protection and the Ministry of Tourism. Collaboration among these institutions is essential for the development of integrated management strategies that combine heritage conservation with climate adaptation, natural hazard preparedness, and sustainable visitor management.

Concurrently, the preservation of the monument necessitates an interdisciplinary approach, as conservation decisions encompass not only archaeological concerns but also considerations pertaining to structural safety, environmental exposure, and risk

management. For this reason, cooperation between archaeologists, conservators, civil engineers, geologists, and environmental specialists is essential to ensure that interventions are based on both scientific evidence and practical conservation needs (Stanley-Price et al., 2003; Bouras, 2007).

The involvement of local communities and educational institutions has been demonstrated to have the capacity to strengthen public awareness and encourage long-term support for conservation efforts. Moreover, in light of the elevated seismic activity characteristic of the Corinth region, it is imperative that preparedness for natural hazards be incorporated into the overarching management strategy. This should encompass the establishment of clearly delineated response procedures, damage documentation protocols, and post-event technical assessments.

The sustainable protection of the monument is contingent upon stable financial support, as heritage conservation is a continuous rather than a one-time process. In addition to national funding, the utilization of European programs related to cultural heritage, climate adaptation, and risk management, as well as broader international support initiatives, could enhance the long-term resilience of the monument.

In order to ensure the preservation of the Temple of Apollo, it is necessary to implement a multifaceted approach that incorporates technical protection measures, institutional coordination, scientific collaboration, and long-term strategic planning. This comprehensive strategy is essential to safeguard the monument against future environmental and operational challenges.

6.5 Implementation Framework for Preservation Measures

The effective preservation of the Temple of Apollo necessitates the implementation of integrated and preventive conservation measures that address both current and projected climate-related risks. In order to enhance the monument's long-term resilience, the subsequent section proposes a series of priority preservation and adaptation strategies. These strategies are informed by the hazard, vulnerability, and risk assessment that was discussed in the preceding chapter. In the context of sustainable cultural heritage preservation, the proposed measures highlight the importance of continuous monitoring, preventive conservation, structural evaluation, environmental management, and institutional collaboration.

Preservation/ Adaptation Measure	Objective	Related Hazard or Stressor	Implementation Priority	Expected Outcome	Responsible Authority
Continuous environmental monitoring	Identification and assessment of long-term environmental deterioration trends affecting the monument materials	Extreme heat, humidity fluctuations, atmospheric pollution, and thermal stress	High	Early detection of material deterioration processes affecting the oolitic limestone surfaces	Ministry of Culture / Ephorate of Antiquities of Corinthia
Periodic structural assessment and crack monitoring	Evaluation of structural stability and seismic vulnerability of the standing architectural remains	Seismic activity and structural stress	Very High	Improved preventive conservation and enhancement of structural resilience against seismic hazards	Ephorate of Antiquities of Corinthia / Structural Engineers
Reorganization of visitor access and relocation of parking area	Reduction of indirect anthropogenic pressure on the monument and surrounding archaeological landscape	Tourism activity, vehicle circulation, and human-induced disturbance	Medium	Improved protection of the archaeological setting and reduction of environmental and physical stress factors	Ministry of Culture / Ephorate of Antiquities of Corinthia / Local Authorities
Periodic cleaning and removal of biological growth	Prevention of bio-deterioration and surface material decay	Humidity, biological colonization, and moisture retention	Medium	Improved preservation and stabilization of exposed stone surfaces	Conservation Specialists
Emergency preparedness and response planning	Strengthening response capacity during extreme hazard events	Earthquakes and extreme climatic phenomena	High	Reduction of post-disaster damage and improvement of emergency intervention efficiency	Ministry of Culture / Ephorate of Antiquities of Corinthia / Ministry of Climate Crisis and Civil Protection
Integration of climate adaptation strategies into heritage management planning	Enhancement of long-term monument resilience and sustainability	Combined climate-related hazards (CCTHaz)	High	Development of a sustainable and adaptive preservation framework for the monument	Ministry of Culture

Periodic reassessment of hazard and vulnerability indicators	Continuous updating and prioritization of conservation needs	Heritage Hazard Index (HHI), climate variability, and evolving environmental stressors	Medium	Adaptive and risk-informed conservation planning	Research Institutions and Conservation Specialists
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Table 13. Proposed Preservation and Adaptation Measures for the Temple of Apollo

The suggested implementation framework prioritizes measures that address risks determined to exert the most influence on the monument's structural integrity and material preservation. Environmental monitoring, structural evaluation, and preventative conservation receive particular attention since they facilitate the early identification of deterioration processes and enable long-term risk mitigation. Furthermore, the incorporation of measures for climate adaptation and recurring reassessment processes underscores the necessity for sustainable and adaptable approaches to heritage management in response to changing environmental and climatic conditions.

7 Conclusions

The present study examined the impacts of climate change on the Temple of Apollo at Ancient Corinth, employing a risk assessment framework that integrated archaeological, architectural, geological, and environmental data. By applying a qualitative and semi-quantitative methodology, the research evaluated the interaction between climate-related hazards, seismic activity, exposure conditions, and monument vulnerability.

The findings indicated that the monument's vulnerability is primarily associated with the combined influence of climatic stressors and seismic hazards. The Temple of Apollo remains highly vulnerable to long-term environmental deterioration due to the intrinsic properties of its oolitic limestone, prolonged weathering processes, and its location within the highly active tectonic environment of the Corinth Rift. The research highlighted the need for systematic environmental monitoring, preventive maintenance, and the implementation of adaptation measures to mitigate deterioration risks. Furthermore, the study emphasized the importance of interdisciplinary approaches to cultural heritage management in addressing existing threats and strengthening the monument's long-term resilience.

7.1 Key Findings

The research showed that climate change constitutes a significant and growing threat to the conservation of the Temple of Apollo in Ancient Corinth. Among the identified hazards, seismic activity and extreme heat emerged as the highest-priority threats, while increasing aridity, humidity variability, and atmospheric pollution were identified as important secondary drivers of material deterioration.

The study also demonstrated that the oolitic limestone used in the temple is particularly vulnerable to moisture intrusion, thermal stress, salt crystallization, and biological colonization, while continuous seismic activity increases the structural vulnerability of the surviving architectural elements, especially the standing columns and epistyles. The study also demonstrated that climate-related hazards should not be interpreted independently. The interaction between thermal stress, aridity, moisture fluctuations, and seismic loading creates compound risks capable of accelerating both material degradation and structural instability.

Furthermore, the findings revealed that climatic and seismic hazards act synergistically, intensifying the overall deterioration of the monument. The application of integrated risk assessment tools, such as the Combined Climate Threat Hazard Index (CCTHaz) and the Heritage Hazard Index (HHI), proved useful for assessing vulnerability and prioritizing conservation measures.

Finally, the study highlighted the need for conservation strategies that prioritize preventive maintenance, systematic environmental monitoring, periodic risk reassessment, and adaptive heritage management planning.

7.2 Challenges and Limitations

Several limitations should be acknowledged. First, the study relied primarily on published climatic, geological, and environmental datasets rather than on long-term in situ monitoring records collected directly from the monument. Second, the applied methodology was semi-quantitative and therefore provides relative rather than absolute measurements of risk. Third, uncertainties associated with future climate projections under RCP scenarios may influence the magnitude of projected hazards. Finally, the absence of

detailed structural modelling restricted the evaluation of the monument's mechanical response to combined climatic and seismic stresses.

Furthermore, due to the scale of the temple and the lack of appropriate access infrastructure, a comprehensive assessment of the monument's state of conservation could not be fully conducted. The absence of previous systematic condition surveys also limited the possibility of evaluating deterioration trends over time.

A further limitation concerns the availability of continuous site-specific environmental measurements. A fixed data logger had been installed at the Temple of Apollo and was used for the continuous monitoring of air temperature and relative humidity. However, the device was subsequently lost, and the corresponding measurements were therefore no longer available for the present analysis. This limited the possibility of using a continuous in-situ environmental data-set for comparison with the broader climatic and environmental data employed in the study.

In addition, the analysis of structural, seismic, and geological parameters was based primarily on published literature and available data, without specialized technical or geotechnical field investigations. Similarly, atmospheric pollution and sea-salt deposition were not examined through direct measurements but were assessed indirectly based on environmental conditions, published studies, and observed deterioration patterns.

Finally, the study did not include economic evaluations, cost analyses, or detailed intervention plans, as its primary objective was the development of a risk-based conservation and management framework.

7.3 Recommendations and Future Research Directions

Based on the findings and limitations of this study, several recommendations can be proposed to support both the long-term conservation of the Temple of Apollo in Ancient Corinth and the advancement of research on the impacts of climate change on archaeological heritage.

A primary priority should be the establishment of long-term environmental and structural monitoring systems capable of recording temperature fluctuations, relative humidity, atmospheric pollutant concentrations, moisture accumulation, salt deposition, and structural movements. Continuous monitoring would provide valuable data for

understanding the relationship between environmental conditions and deterioration processes, while supporting evidence-based conservation decision-making.

In particular, the re-installation of a fixed environmental data logger at the Temple of Apollo should be considered as a priority measure for the continuous recording of air temperature and relative humidity. The resulting in-situ measurements could be compared with satellite-derived and gridded climatic datasets, providing a more detailed assessment of site-specific environmental conditions and allowing the representativeness of broader-scale climate data to be evaluated at the monument scale.

Further research should include detailed material characterization, geological and geotechnical investigations, and comprehensive structural assessments to improve understanding of the mechanical behaviour and long-term vulnerability of the oolitic limestone and the surviving architectural elements. In this context, the metal components installed during previous restoration interventions should be re-evaluated to assess their compatibility and long-term performance. In addition, a systematic condition survey and the development of a comprehensive conservation plan would support the effective planning of future interventions.

The application of advanced digital documentation techniques, including photogrammetry, LiDAR scanning, three-dimensional modelling, and GIS-based monitoring systems, could significantly enhance the documentation and long-term monitoring of deterioration phenomena. Future research should also incorporate direct measurements of atmospheric pollution and marine salt deposition to better quantify their contribution to material deterioration and evaluate their interaction with climatic and seismic factors.

In particular, future environmental monitoring could be expanded to include air-quality parameters such as particulate matter (PM_{2.5} and PM₁₀), nitrogen dioxide (NO₂), ozone (O₃), and sulfur dioxide (SO₂). The integration of these measurements with temperature and relative humidity records would provide a more comprehensive site-specific environmental data-set and could support the investigation of relationships between atmospheric pollution, climatic conditions, and observed deterioration processes.

The development of a long-term, site-specific environmental data-set would also provide an opportunity for further development of the risk assessment methodology

applied in the present study. Future research could investigate how in-situ observations can be integrated with the climate-based hazard indicators and risk assessment framework used in the approach of Kapsomenakis et al. Such an approach could complement the regional and projected climate information with direct observations from the monument, contributing to a more site-specific assessment of climate-related risks.

From a management perspective, climate change adaptation should be more systematically integrated into cultural heritage protection policies at local, regional, and national levels. Strengthening collaboration among archaeologists, conservators, engineers, geologists, environmental scientists, and policy makers is essential for the development of effective and adaptive conservation strategies.

In addition, economic considerations should be incorporated into heritage management and conservation planning. The development of frameworks that combine risk assessment with cost-benefit and life-cycle cost analyses could support the prioritization of conservation measures and the more efficient allocation of available resources.

Finally, the application of similar risk-based assessment frameworks to other Archaic stone monuments located in climatically and seismically sensitive regions of the Mediterranean could contribute to a broader understanding of climate-related risks affecting cultural heritage. Comparative studies would also support the refinement of standardized methodologies for risk assessment, monitoring, and conservation planning, contributing to the long-term protection of archaeological monuments.

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Appendix A: Condition Survey and Photographic Catalogue



Figure A.1. Overall condition of Columns C1–C5, front elevation.



Figure A.2. Overall condition of Columns C5–C7.



Figure A.3. Overall condition of the surviving columns and architrave, viewed from the interior.

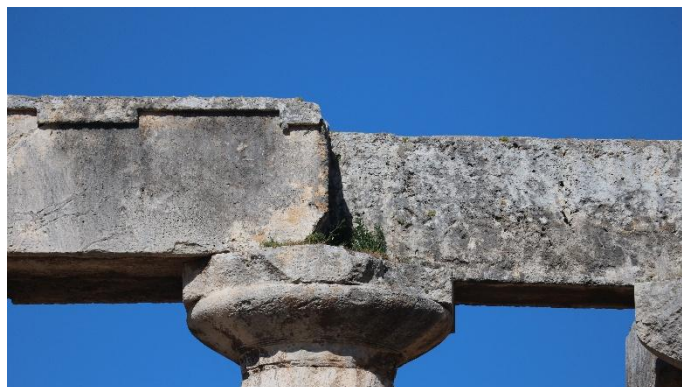
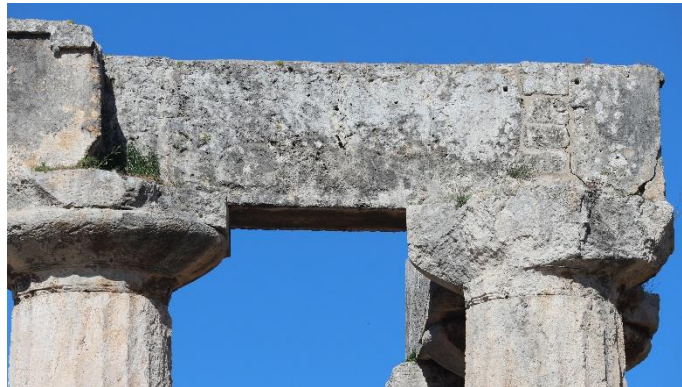




Figure A.4-6. General condition of the architrave and adjacent Doric capitals.

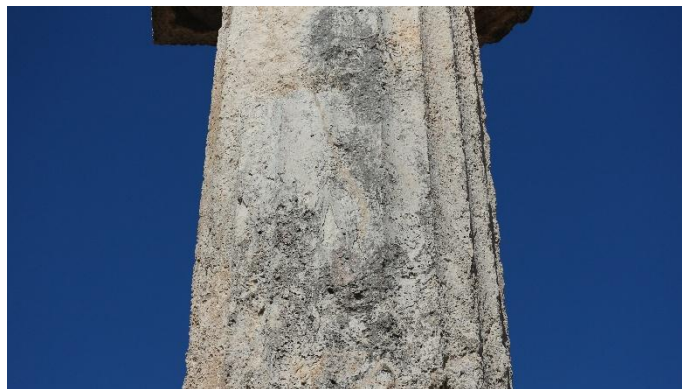






Figure A.7-14. State of preservation of Column 1 (C1), front elevation.





Figure A. 15-20. State of preservation of Column 2 (C2), front elevation.

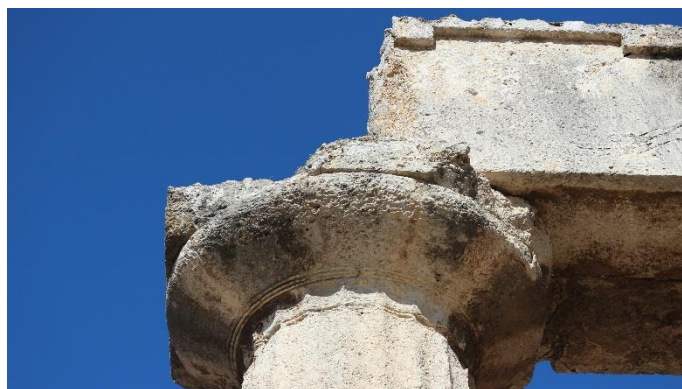
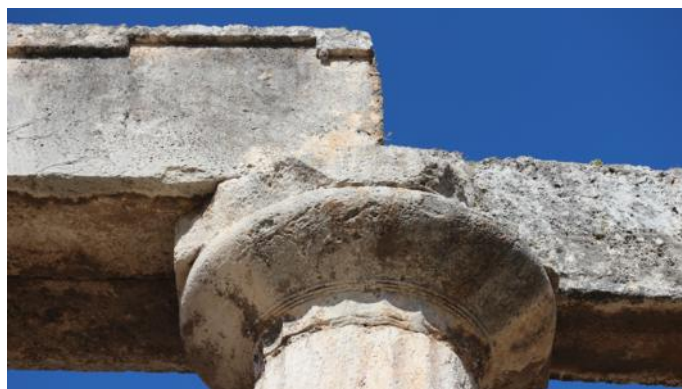






Figure A. 21-28. State of preservation of Column 3 (C3), front elevation.



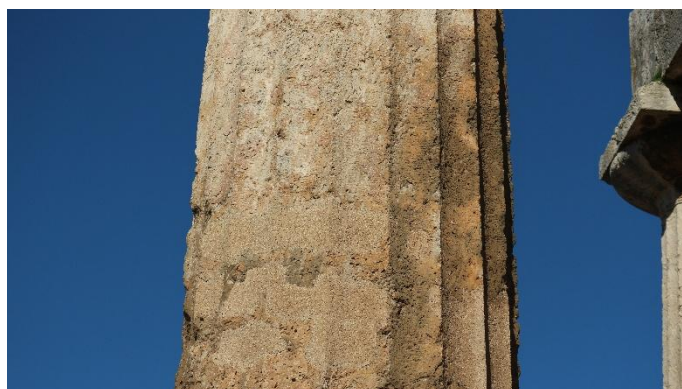
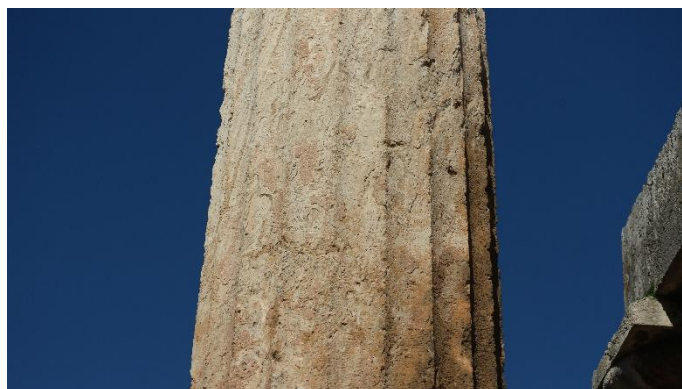




Figure A. 29-37. State of preservation of Column 4 (C4), front elevation.

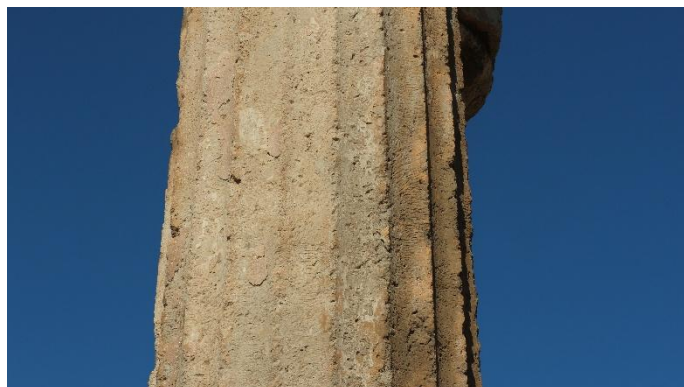
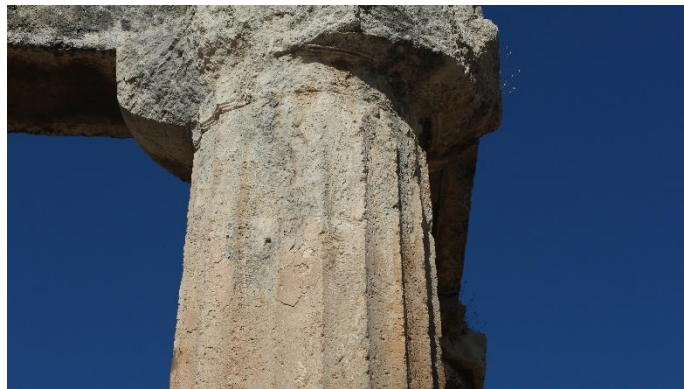




Figure A. 38-45. State of preservation of Column 5 (C5), front elevation.

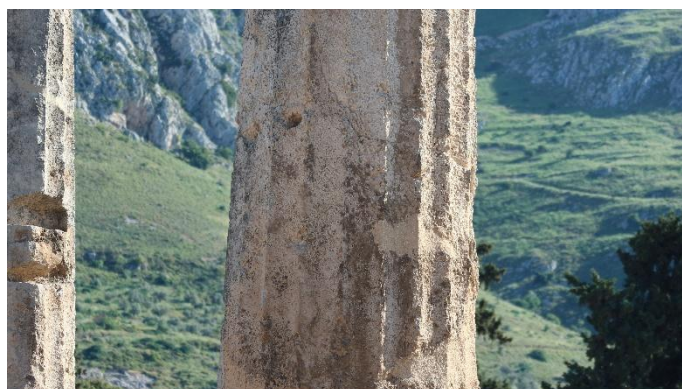
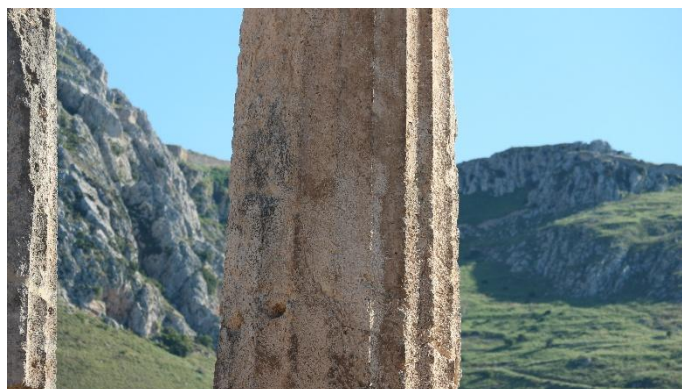
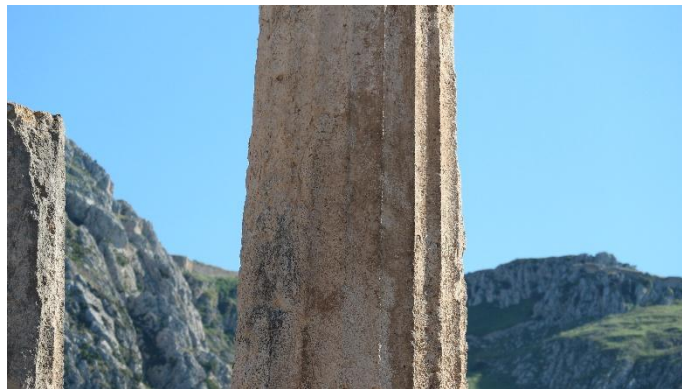




Figure A.46-51. State of preservation of Column 1 (C1), viewed from the interior.

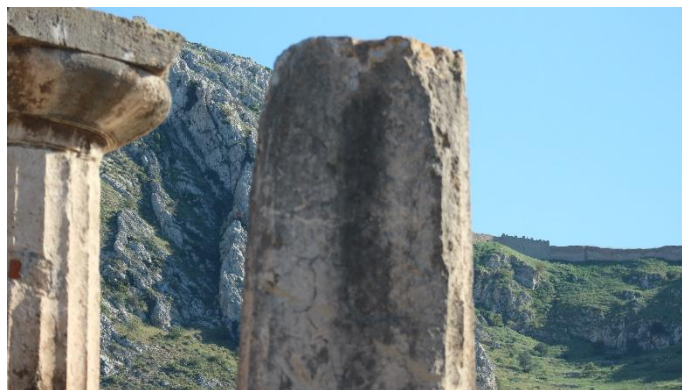




Figure A.52-55. State of preservation of Column 2 (C2), viewed from the interior.

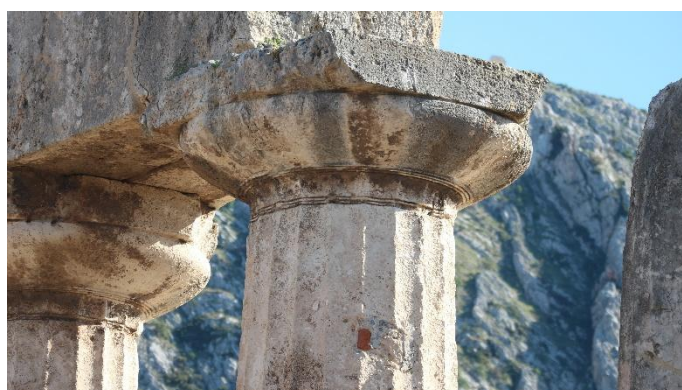
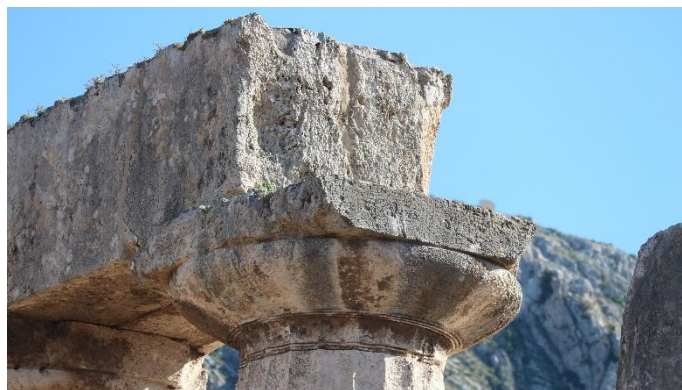
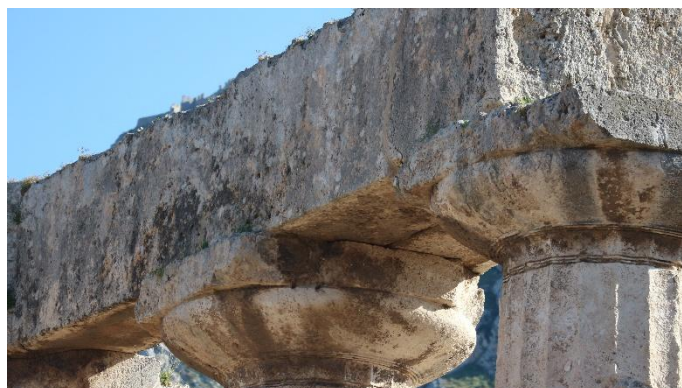




Figure A.52-55. State of preservation of Column 3 (C3), viewed from the interior.



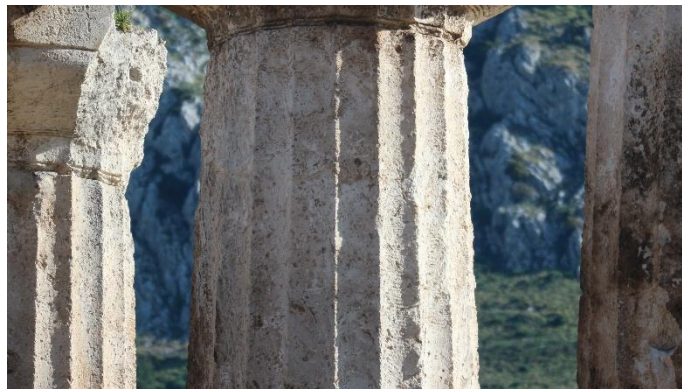
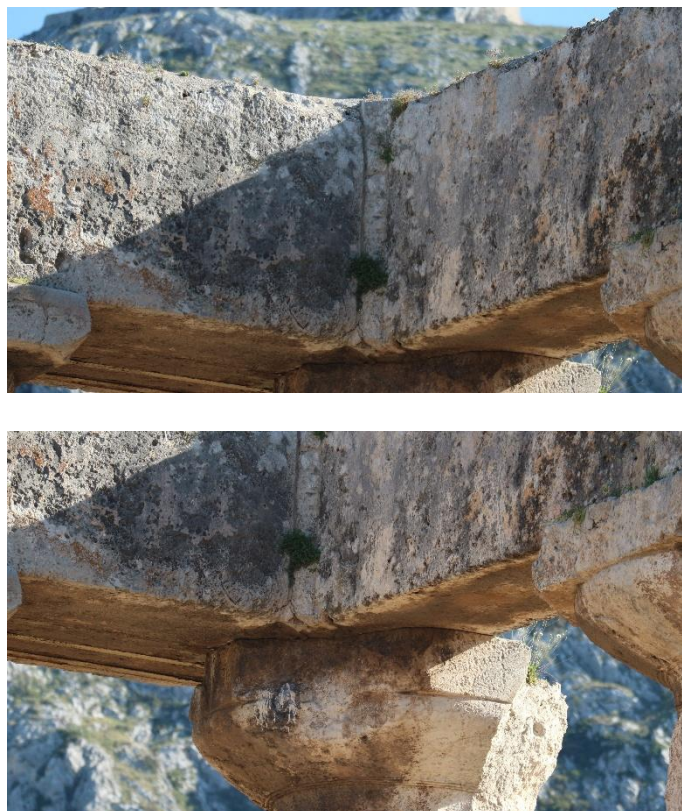




Figure A.56-62. State of preservation of Column 4 (C4), viewed from the interior.



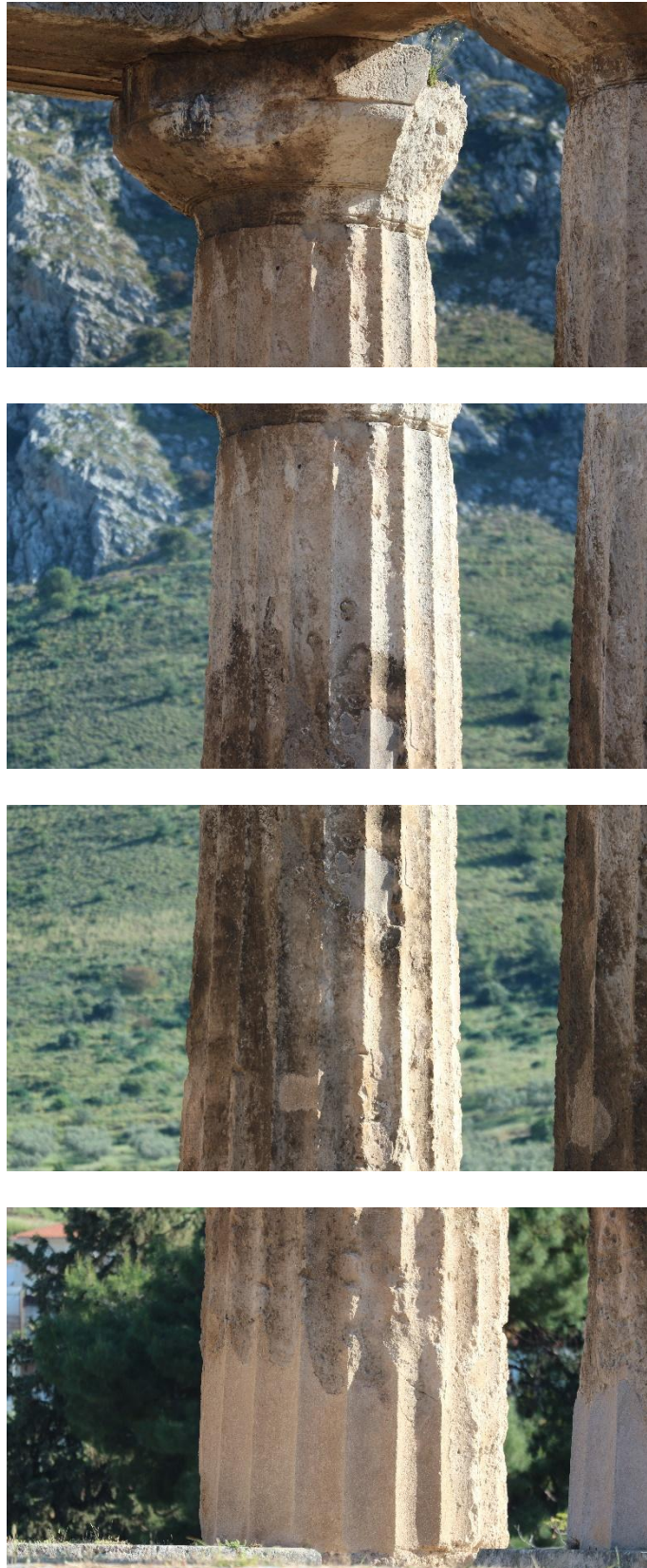


Figure A.63-68. State of preservation of Column 5 (C5), viewed from the interior.

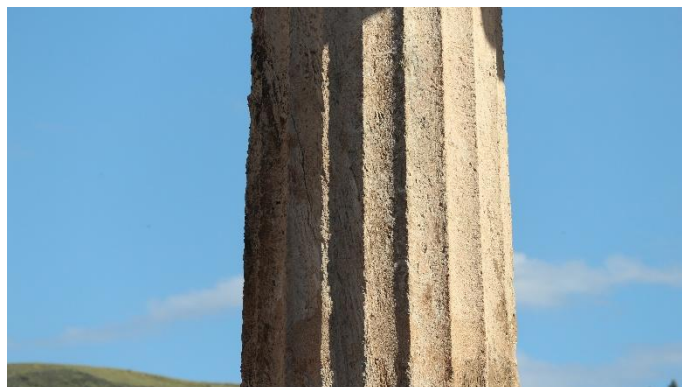
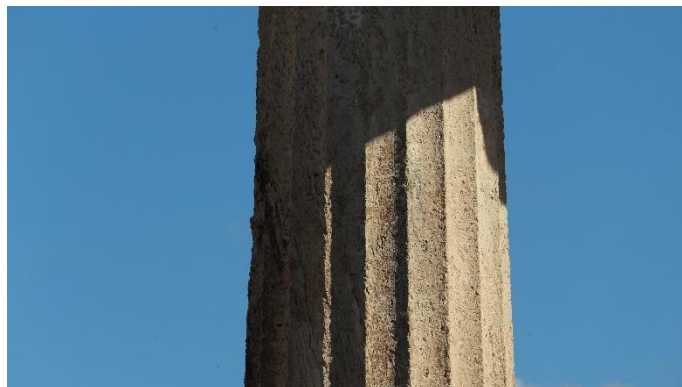
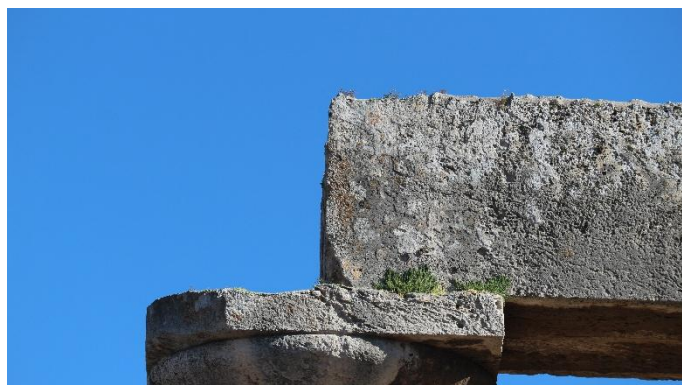




Figure A.69-75. State of preservation of Column 6 (C6), viewed from the interior.



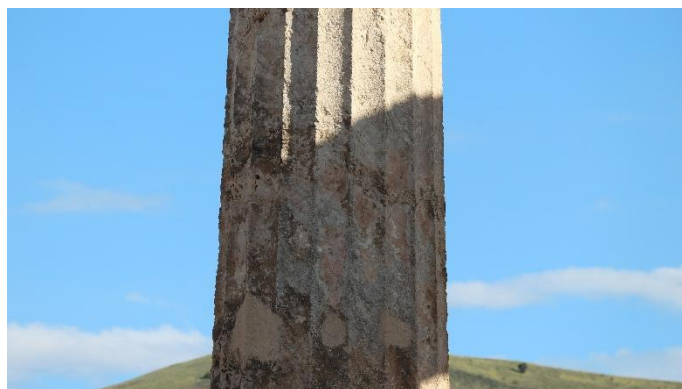
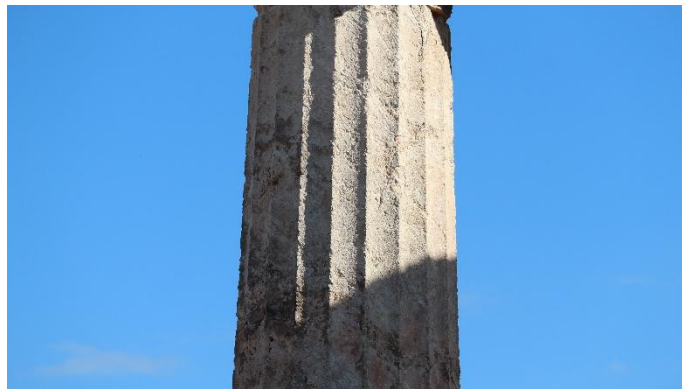


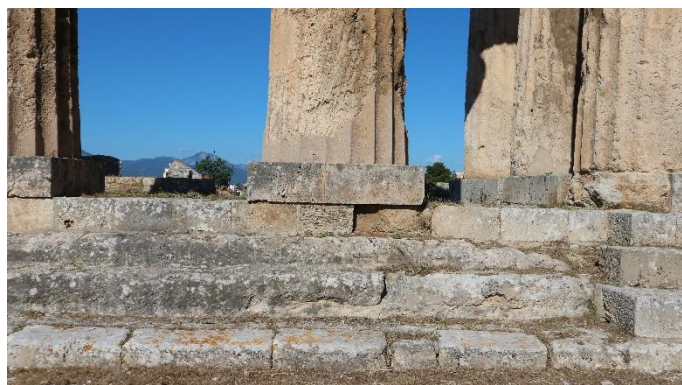
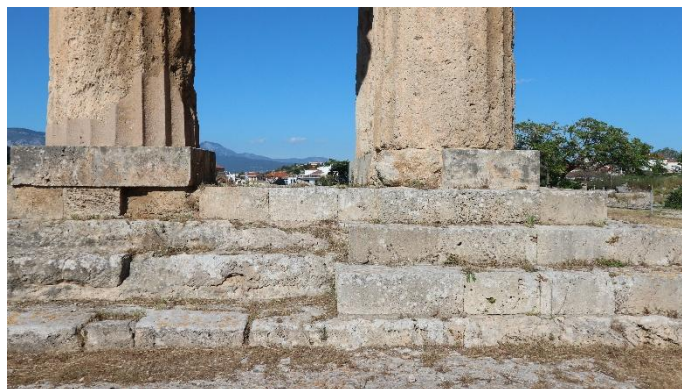


Figure A.76-81. State of preservation of Column 7 (C7), viewed from the interior.





Figure A.82-85. General condition of the architrave and adjacent Doric capitals, viewed from the interior.



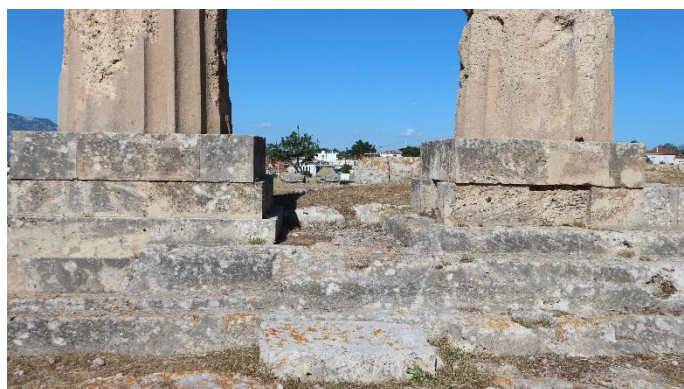
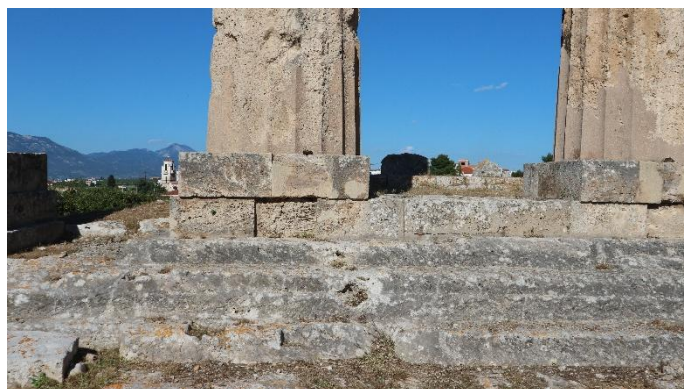
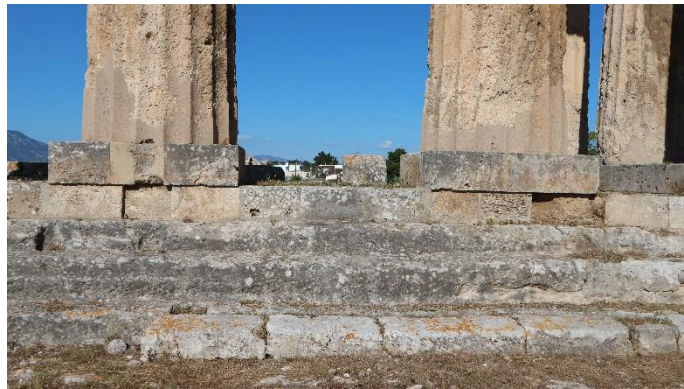




Figure A.86-94. General condition of the stepped foundation platform (krepidoma).

Appendix B: Climate Datasets, Indicators, and Scenario Tables

B1. Data Sources

Climate data were obtained from the “*DEAR-Clima*” platform, which provides both historical datasets and future projections for multiple environmental parameters. The reference period (1971–2000) was used as a baseline for comparison with future scenarios (RCP 4.5 and RCP 8.5).

B2. Climate Indicators

Indicator	Description	Hazard
TX ₃₇	Days with Tmax > 37°C	Extreme heat
TN ₀	Days with Tmin < 0°C	Frost
PR ₉₉	Extreme precipitation events	Heavy rainfall
AI	Aridity Index	Drought
FWI ₄₅	Wildfire Hazard Sub-Index	Wildfire
SLR	Coastal Flooding Sub-Hazard Index	Sea Level Rise

B3. Methodological Summary

For all parameters, values for future periods were calculated relative to the reference period using percentage change:

$$RC(\%) = \frac{Value_final - Value_initial}{Value_initial} \times 100$$

RC (%) = Relative Change (%)

Extreme temperature indices (TX₃₇, TN₀):

Count of days per decade exceeding thresholds

Extreme precipitation (PR₉₉):

Identification of events exceeding the 99th percentile of daily rainfall

Aridity Index (AI):

$$AI = \frac{\sum_{m=1}^{12} (P_m)}{\sum_{m=1}^{12} (PET_m)}$$

P_m: Monthly precipitation (mm), representing the total amount of rainfall recorded for each month

PET_m: Monthly potential evapotranspiration (mm), representing the amount of water that could be evaporated and transpired under prevailing climatic conditions

Potential evapotranspiration (PET) was calculated using the Thornthwaite method, using annual temperature values.

$$I = \sum_m \left(\frac{T_m}{5} \right)^{1.514}$$

$$a = 0.000000675 I^3 - 0.000077 I^2 + 0.01792 I + 0.49239$$

$$PET_m = 16 \left(\frac{I}{10 T_m} \right)^a$$

$$AI = \frac{\sum PET_m}{\sum P_m}$$

B4. Scenario Results

Extreme Heat

Scenario	Period	Total Days	Average Days/Year	Relative Change (%)
Reference	1971–2000	457	15.23	–
RCP 4.5	2021-2030	263	26.3	+72.65
RCP 4.5	2041-2050	339	33.9	+122.54
RCP 4.5	2091-2100	393	39.3	+157.99
RCP 8.5	2021-2030	263	26.3	+72.65
RCP 8.5	2041-2050	436	43.6	+186.21
RCP 8.5	2091-2100	857	85.7	+462.58

Number of days with maximum temperature exceeding 37°C (TX37), including average annual values and relative change.

Frost Days

Scenario	Period	Total Days	Average Days/Year	Relative Change (%)
Reference	1971–2000	349	11.63	–
RCP 4.5	2021-2030	63	6.3	–45.85
RCP 4.5	2041-2050	61	6.1	–47.56
RCP 4.5	2091-2100	52	5.2	–55.30
RCP 8.5	2021-2030	123	12.3	+5.73
RCP 8.5	2041-2050	81	8.1	–30.37
RCP 8.5	2091-2100	4	0.4	–96.56

Number of frost days (TN0: days with minimum temperature below 0°C), including average annual values and relative change.

Heavy Precipitation

Scenario	Period	PR99 threshold (mm)	Days/Year (>PR99)	Relative Change (%)
Reference	1971–2000	61.62	6.0	–
RCP 4.5	2021-2030	61.77	5.0	–16.67
RCP 4.5	2041-2050	52.39	6.0	0.00
RCP 4.5	2091-2100	40.58	5.0	–16.67
RCP 8.5	2021-2030	55.92	7.0	+16.67
RCP 8.5	2041-2050	47.48	5.0	–16.67
RCP 8.5	2091-2100	43.58	4.0	–33.33

Extreme precipitation (PR99), expressed as the number of days exceeding the 99th percentile of daily precipitation.

Aridity

Scenario	Period	Mean I	Mean α
RCP 4.5	2021-2030	39.2	1.12
RCP 4.5	2041-2050	40.4	1.14
RCP 4.5	2091-2100	43.0	1.17
RCP 8.5	2021-2030	37.6	1.09
RCP 8.5	2041-2050	41.0	1.14
RCP 8.5	2091-2100	50.0	1.28

Thornthwaite Parameters (Mean Values)

Scenario	Period	Mean Annual Precipitation (ΣPm)	Mean Annual PET (ΣPETm)	AI Value
RCP 4.5	2021-2030	12.55	95.24	0.125
RCP 4.5	2041-2050	13.07	98.59	0.163
RCP 4.5	2091-2100	8.58	104.20	0.130
RCP 8.5	2021-2030	16.36	92.65	0.100
RCP 8.5	2041-2050	10.05	99.78	0.085
RCP 8.5	2091-2100	7.22	121.90	0.072

Mean annual precipitation (ΣPm) and potential evapotranspiration (ΣPETm) used for the calculation of the Aridity Index (AI).

B5. HHI Results

RCP 4.5

For 2021-2030:

$$HHI = CCTHaz + \sqrt{(CCTHaz) \times (SHaz)}$$

$$HHI = 7 + \sqrt{7 \times 3}$$

$$HHI = 7 + \sqrt{21}$$

$$HHI = 7 + 4.58$$

$$HHI = 11.58$$

For 2041-2050 & 2091-2100:

$$HHI = CCTHaz + \sqrt{(CCTHaz) \times (SHaz)}$$

$$HHI = 8 + \sqrt{8 \times 3}$$

$$HHI = 8 + \sqrt{24}$$

$$HHI = 8 + 4.90$$

$$HHI = 12.90$$

RCP 8.5

For 2021-2030 & 2041-2050 & 2091-2100:

$$HHI = CCTHaz + \sqrt{(CCTHaz) \times (SHaz)}$$

$$HHI = 8 + \sqrt{8 \times 3}$$

$$HHI = 8 + \sqrt{24}$$

$$HHI = 8 + 4.90$$

$$HHI = 12.90$$

[illegible]

Geological map of the Corinth region showing lithological formations and tectonic structures, with the location of the Temple of Apollo indicated (elekkas.gr, n.d.).

Appendix D: Environmental and Structural Monitoring Templates

D1. Environmental Monitoring Record Sheet

Date	Air Temperature (°C)	Relative Humidity (%)	Rainfall (mm)	Wind Conditions	Air Pollution Indicators	Observations

Parameter	Recommended Frequency
Air Temperature	Continuous (Data Logger)
Relative Humidity	Continuous (Data Logger)
Rainfall	Monthly
Wind Exposure	Monthly
Air Pollution	Monthly
Biological Colonization	Quarterly

D2. Structural Condition Monitoring Form

Monument Element Identification		
Inspection Date	Inspector	Weather Conditions

Structural Assessment Table						
Architectural Element	Condition	Cracks	Displacement	Material Loss	Biological Growth	Risk Level
Column 1						
Column 2						
Column 3						
Column 4						
Column 5						

Column 6						
Column 7						
Architrave						
Foundation Area						

Risk Classification	
Classification	Description
Low	No immediate intervention required
Moderate	Continued monitoring required
High	Detailed investigation recommended
Very High	Immediate conservation action required

D3. Biological Colonization Monitoring Form

Location	Type of Growth	Surface Coverage (%)	Moisture Presence	Action Required

Types of Colonization

Lichens

Mosses

Algae

Higher Plants

Microbial Biofilms

D4. Seismic Event Inspection Form

(To be completed following significant seismic activity)

Date of Event	Magnitude	Distance from Site	Initial Observations

Post-Seismic Assessment Checklist

- ☐ New cracks observed
- ☐ Existing cracks widened
- ☐ Stone displacement detected
- ☐ Structural instability observed
- ☐ Material detachment recorded
- ☐ Emergency intervention required

D5. Annual Conservation Review Checklist

Environmental Monitoring

- ☐ Temperature data analysed
- ☐ Relative humidity data analyzed
- ☐ Rainfall records reviewed
- ☐ Air pollution records reviewed
- ☐ Biological growth assessed

Structural Monitoring

- ☐ Crack survey completed
- ☐ Structural movement assessed
- ☐ Stone deterioration mapped
- ☐ Restoration elements inspected

Management Actions

- ☐ Risk assessment updated
- ☐ Conservation priorities revised
- ☐ Monitoring programme updated
- ☐ Findings documented and archived

Author’s Statement:

I hereby expressly declare that, according to the article 8 of Law 1559/1986, this dissertation is solely the product of my personal work, does not infringe any intellectual property, personality and personal data rights of third parties, does not contain works/contributions from third parties for which the permission of the authors/beneficiaries is required, is not the product of partial or total plagiarism, and that the sources used are limited to the literature references alone and meet the rules of scientific citations.

