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An Approach to Risk Assessment and Planned Preventative Maintenance of Cultural Heritage: The Case of the Hypogeum Archaeological Site of Sigismund Street (Rimini, Italy)

Anna Casarotto , Sara Fiorentino * and Mariangela Vandini

Department of Cultural Heritage, University of Bologna, Ravenna Campus, Via degli Ariani 1, 48121 Ravenna, Italy; anna.casarotto3@unibo.it (A.C.); mariangela.vandini@unibo.it (M.V.)
* Correspondence: sara.fiorentino2@unibo.it

Abstract

This study presents a comprehensive approach to risk management and planned preventative maintenance (PPM) for cultural heritage, focusing on the hypogeum archaeological site beneath the Chamber of Commerce in Rimini, Italy. Hypogeal environments pose unique conservation challenges due to their microclimates, biological threats, and structural vulnerabilities. Applying the ABC Method—developed by ICCROM and CCI—this research systematically identifies, analyzes, and prioritizes risks associated with agents of risks. The methodology was complemented by the Nara Grid to assess the site's authenticity and cultural value, aiding in the delineation of risk areas and informing strategic conservation priorities. The study identifies efflorescence formation, flooding risks, and lack of management guidelines as extreme threats, proposing tailored treatments and practical interventions across multiple layers of control. Through environmental monitoring, empirical analysis, and a multidisciplinary framework, the research offers a replicable model for sustainable conservation and preventive heritage management in similar subterranean contexts.

Keywords: preventive conservation strategies; ABC method; heritage preservation; Nara Grid authenticity; risk assessment

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Academic Editor: Dmitry A. Ruban

Received: 24 June 2025
Revised: 14 August 2025
Accepted: 14 August 2025
Published: 23 August 2025

Citation: Casarotto, A.; Fiorentino, S.; Vandini, M. An Approach to Risk Assessment and Planned Preventative Maintenance of Cultural Heritage: The Case of the Hypogeum Archaeological Site of Sigismund Street (Rimini, Italy). *Heritage* **2025**, *8*, 344. https://doi.org/10.3390/heritage8090344

1. Introduction

Cultural and natural hypogeal sites are a unique and valuable part of world heritage. The term hypogeum describes a variety of subterranean locations, including man-made (e.g., catacombs, tombs, crypts, foundations, etc.) and natural (e.g., caverns), constructed above ground and covered with earth or excavated into the rocks.

Hypogeal sites face several conservation challenges, primarily due to their unique microclimatic conditions and biological threats. The primary concerns include microclimatic issues, biological growth, human impact, and root damage from surrounding vegetation. Hypogeal settings often provide stable climatic conditions that are not detrimental to preservation, but it is important to be aware that exposure to artificial or natural light or unexpected fresh air infiltrations could upset this delicate balance [1–4]. The low-or absent natural light and the abundance of organic and inorganic nutrients, as well as soluble salts, are, in fact, important features to be considered, which could be transported by percolating water from seepage and soil or by visitors.

The crystallization of salts is one of the frequently occurring factors of the deterioration of porous materials in hypogeal sites [5–7]. Efflorescences and sub-efflorescences can cause the loss of material from superficial to inner layers, through powdering, detachments, blistering, exfoliation, and flaking. Common deliquescent salts are sulfates, chlorides, and nitrates, which can often be found in association with cement that is used for restoration interventions [8], percolation of rainwater from the surrounding soils [9], and wetness or deposition of airborne particles on surfaces [10].

The proliferation of biodeteriogens is another detrimental factor for preservation within hypogeal sites [2,11,12]. When liquid water is present on surfaces along with nutrients, natural or artificial light, and inadequate indoor ventilation, biodeteriogens are more likely to be present. Biofilm, a complex mucosal matrix in which biodeteriogens are lodged, typically takes the shape of coloured patinas and may have an unfavourable visual effect. Once the biofilms are formed, heterotrophic biodeteriogen, like actinobacteria and fungi, can colonize the surface by exploiting the metabolites and biomass that are produced by cyanobacteria [13–15]. Biocides are used for control, but they can lead to the emergence of resistant species [3,11].

As far as human impact is concerned, visitor access can exacerbate degradation due to changes in microclimatic conditions caused by a human presence. Balancing visitor access with conservation requires careful planning. Strategies include defining visitor numbers and durations to minimize impact on the hypogeal environment [1,4]. Moreover, eye-tracking technologies have been used to study visitor engagement and optimize lighting and presentation of artefacts, ensuring that visitors focus on well-preserved and adequately lit areas [16].

Last, the growth of tree roots can cause structural damage to hypogeal sites, particularly in areas with historical gardens. Roots can penetrate and destabilize underground structures, necessitating careful management of surrounding vegetation [3].

The literature shows that effective conservation strategies must comprehensively address these issues through environmental monitoring, sustainable visitor management, and vegetation control to preserve hypogeal sites. This paper presents a study devoted to the management of risks inside hypogeal sites based on the ABC Method, established by ICCROM and CCI [17]. The methodology is applied to the archaeological site of the Chamber of Commerce in Rimini (Emilia–Romagna, Italy), a Roman hypogeal site which suffered from different decay processes. The case study, research aims, and methodology are described in the following section.

The ABC method defines risk management as all the actions that are taken to prepare for possible negative impacts to cultural heritage. It is an ongoing, cyclic process for monitoring the risks and adjusting our actions to minimize negative impacts as shown in Figure 1. According to the method, risk management is organized into six phases: context, identify, analyze, evaluate, treat, and monitor.

To date, no case studies have been found in the literature in which the ABC method has been applied and adapted to hypogeal sites. As the analysis of the available literature provided in this section shows, the approach to risk management for this type of context is still limited and strongly conditioned by the peculiarities and criticalities that, taken individually, each site presents. As highlighted in the discussion of the results, the ABC method can lead towards a more specific evaluation of multi-risk scenarios associated with underground environments, allowing, through this perspective, reasoning in strategic terms of preventive conservation, considering the available resources and the medium-long term effectiveness of the proposed solutions.

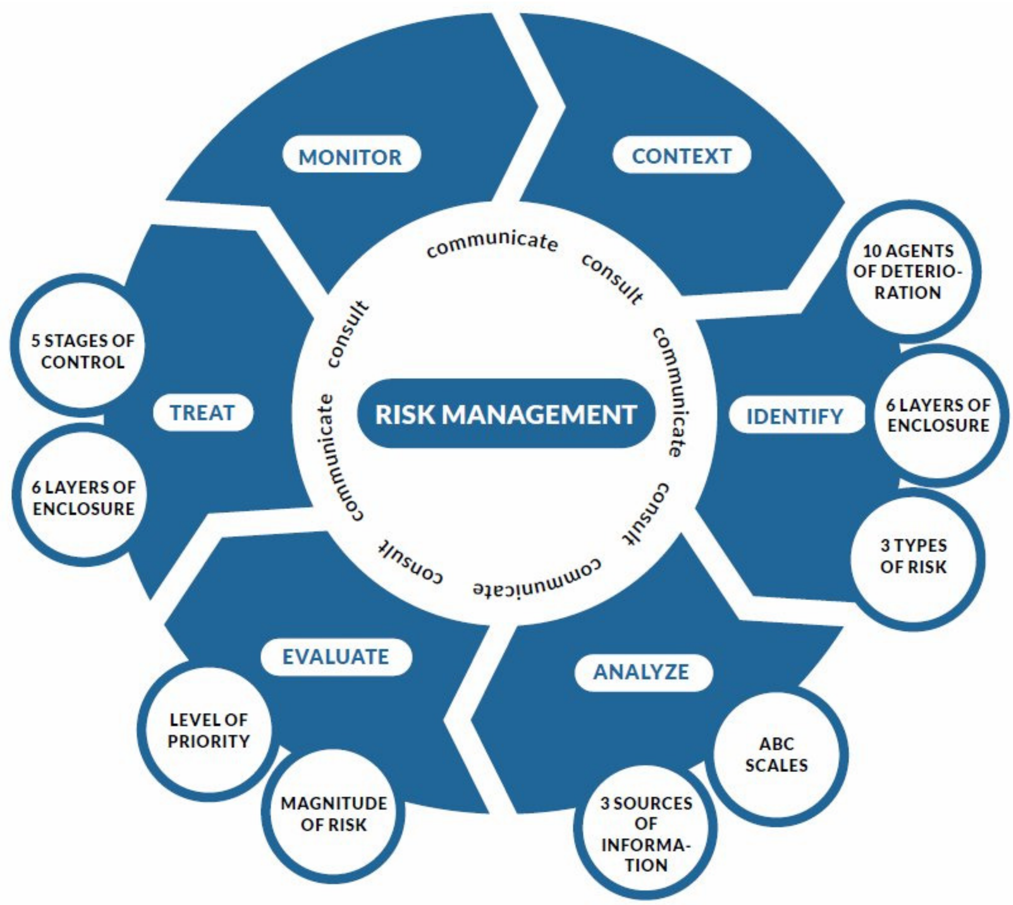


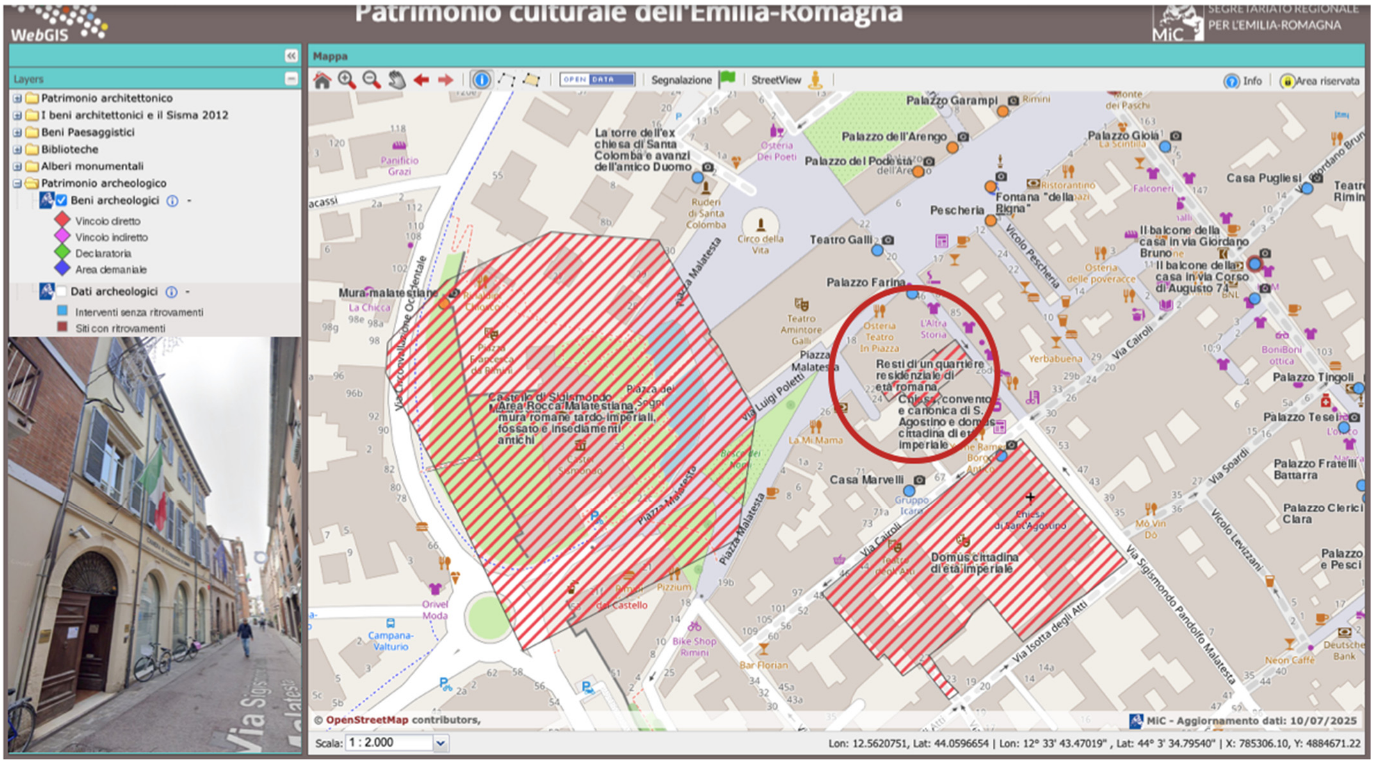
Figure 1. ABC risk management framework [17] p. 15.

2. Materials and Methods

2.1. The Case Study

The site beneath the Chamber of Commerce in Rimini, shown in the modern settlement of the city in Figure 2a, is located in the western quadrant of the Roman-era settlement, within a district bounded by the city walls and main roadways connecting Porta Montanara, the forum, and the Tiberius Bridge as shown in Figure 2b. The insula has been occupied since the late Republican period, as evidenced by several residential structures, including a notable opus signinum floor. In the south-eastern sector, a 35-square-meter polychrome mosaic with floral motifs, stylistically dated to the first half of the 4th century, represents the only surviving evidence of a renovation phase within a context largely marked by Imperial-era remains. In the 5th century, a domus in the eastern sector of the Via Sigismondo excavation was altered to include an apsidal room decorated in opus sectile, which disrupted the public sewer system—highlighting the dominance of private interests over public infrastructure. The building retained a prominent role throughout the 5th and 6th centuries but eventually declined, leading to its abandonment and burial by the early Middle Ages [18–22].

The remains were uncovered during a stratigraphic excavation conducted in 1995–1996, promoted by the Chamber of Commerce and directed by the Archaeological Superintendence of Emilia–Romagna, following earlier surveys and core sampling in 1994 as depicted in Figure 3 [19].



(**a**)

(**b**)

Figure 2. (**a**) Circled in red the extension of the archaeological site in Sigismund Street in the modern city asset of Rimini, Italy. Nearby can be found other recognized archaeological sites known as "*Domus* of the Imperial age" (on the right) and "Area of the Malatesta fortress, imperial Late roman sights, moat and ancient settlements" (on the left side) [23] In the left corner the Google street image of the Chamber of Commerce entrance [24]; (**b**) the blue dot indicates the topographic localization of the excavation in the ancient Roman Ariminum city [19] p. 1.

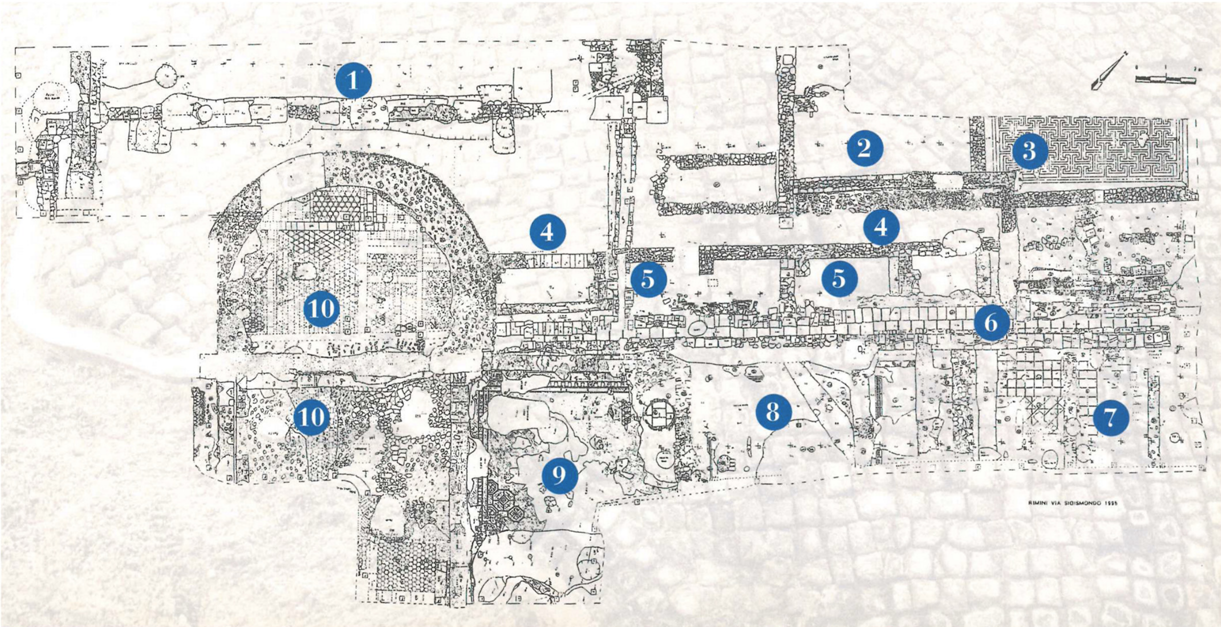


Figure 3. Area of the archaeological excavation. 1–3 Western sector: 1 area with portico, 3 floor in opus signinum of the Republican Era. 4–6 Middle sector: 5 foundation of small adjacent rooms, 6 sewer duct. 7–10 Eastern sector: 7 floors in opus sectile of the Imperial Era, 8–9 mosaic and earthenware floors of late Republican and late Imperial Era, 10 large room with apse and opus sectile floor of late antiquity period [19] p. 2.

Located in the basement of the Chamber of Commerce, the site underwent the first conservative intervention in 2022, followed by an extensive restoration campaign in 2023, prompted by the deteriorated state of the preserved remains. Before this, the last documented conservation effort dated back to March–July 1999, as part of a workshop organized by the former Mosaic Restoration School of Ravenna. Prior to that, only an initial safety intervention had been carried out in 1997 following the excavations [25,26].

While the site exhibits some characteristics typical of subterranean heritage, such as its location below current ground level and the need for specialized conservation approaches, it does not fully conform to the definition of Underground Built Heritage (UBH), which generally refers to intentionally constructed underground spaces with architectural functions [27,28]. In this case, the hypogeal nature of the site is a result of stratigraphic burial rather than deliberate underground construction. Nonetheless, the methodological challenges associated with risk assessment, environmental monitoring, and preventive maintenance are highly consistent with those encountered in UBH contexts. For this reason, a brief discussion of the UBH framework has been included in this section, highlighting both the distinctions and the shared conservation concerns. In recent years, the concept of Underground Built Heritage (UBH) has gained increasing attention in cultural-heritage research, particularly in the fields of architectural conservation, urban archaeology, and risk management. UBH refers to intentionally constructed or adapted underground spaces that hold historical, architectural, or cultural significance [29]. These include cisterns, tunnels, catacombs, hypogea, and other subterranean infrastructures designed for long-term use and often possessing architectural features such as masonry, vaults, or organized circulation systems.

The Underground4value EU project has been instrumental in shaping the definition and assessment of UBH, emphasizing the importance of community engagement, adaptive reuse, and integrated risk assessment in managing and activating these heritage assets [30]. Through case studies across Europe, it has provided methodological guidelines to evaluate

UBH's potential in terms of conservation, tourism, and sustainable development. Risk management plays a central role in UBH conservation. Konsta and Della Torre [31] proposed a comprehensive classification of risks affecting built heritage, distinguishing between structural, environmental, operational, and organizational risks—many of which are applicable to underground contexts. Similarly, Ravan et al. [32] developed a vulnerability assessment framework combining exposure, sensitivity, and adaptive capacity, which can be extended to archaeological and subterranean environments. Despite the clear framework, not all underground sites meet the formal criteria of UBH. Some, particularly archaeological hypogea, are not the result of intentional underground construction but are instead buried due to stratification and urban sedimentation. These sites often lack distinct architectural planning yet present conservation challenges very similar to UBH, such as restricted access, humidity-related deterioration, and long-term environmental instability. In the present study, although the Roman site beneath the Chamber of Commerce in Rimini is not a canonical UBH site—its underground position being the result of historical stratification rather than architectural intention—it shares several risk factors common to UBH, including restricted access, humidity-related decay, and the need for continuous preventive maintenance. For this reason, conservation methodologies developed for UBH contexts remain highly relevant and adaptable to this type of archaeological environment.

2.2. Research Aims and Methodology

The conservative intervention of the archaeological site laid the groundwork for developing a preventive conservation strategy integrated with a comprehensive risk assessment and management plan. Preventive conservation plays a key role in mitigating deterioration, enhancing cultural value, and maximizing the site's economic and educational potential. It encompasses strategies, actions, and informed decisions aimed at balancing heritage protection with public access [33]. Unlike traditional restoration, the approach adopted in the Rimini Chamber of Commerce case study focuses on long-term effectiveness through strategic preventive conservation.

According to ISO 31000 [34], risk management is an ongoing process that includes defining the context, assessing risks (identification, analysis, evaluation), treating risks, and establishing systems for monitoring, communication, and documentation. A comprehensive strategy involves identifying causes of deterioration (e.g., physical forces, humidity, temperature, pollutants, water, UV light, vandalism), evaluating existing layers of protection, assessing the vulnerability of cultural assets, and categorizing risks (sudden, gradual, cumulative) [17]. When effectively integrated, preventive conservation and risk management help extend the lifecycle of heritage assets by identifying and addressing threats early on [35].

While several methodologies exist for evaluating and mitigating heritage risks e.g., [36–39], this study focuses on the ABC method, chosen for its inclusive, heritage-focused approach. Developed by the Canadian Conservation Institute (CCI) and ICCROM in 2016, originally developed to be applied to museum contexts, the ABC method offers a structured, stakeholder-driven framework for identifying, assessing, evaluating, and treating risks. It is designed to be accessible to non-specialists, making it especially suitable for engaging local communities and stakeholders in the conservation process [17,39]. The ABC method is characterized by a systematic and cyclical approach, making it particularly well-suited to address the complex and multifaceted challenges inherent in cultural heritage conservation. It enables dynamic risk management tailored to the specific conditions of each site. The method begins with a comprehensive identification and evaluation of risks that may threaten the heritage asset. Specifically, the method starts by establishing the context, which involves gaining a thorough understanding of the heritage asset, its environment, and vulnerabilities. This phase includes defining the scope of the risk assessment and identifying all relevant stakeholders. Subsequently, potential risks are identified through systematic brainstorming and analysis, encompassing natural hazards, human factors, and environmental threats. Each identified risk is then analyzed and evaluated to determine its likelihood and potential impact, often using scoring systems or other quantitative and qualitative methods to prioritize the severity of risks. To aid in quantifying and comparing risks to cultural heritage, a dedicated tool has been developed based on numeric scales known as the ABC scales. These scales consist of three components: Component 'A' quantifies the frequency of the damaging event or the rate of occurrence of a process, while components 'B' and 'C' jointly quantify the expected loss of value to the heritage asset. The combined values of A, B, and C define the overall magnitude of the risk. Following this evaluation, appropriate risk-treatment strategies are developed and implemented. These strategies may include preventative measures, contingency plans, or other interventions aimed at minimizing potential damage. Throughout the entire process, effective communication with stakeholders is essential, and the risk-management plan requires regular monitoring and updates to remain relevant and effective. The method supports informed decision-making by systematically analyzing risks, thereby enabling heritage professionals to allocate resources efficiently and devise appropriate preservation strategies. Furthermore, the approach encourages collaboration among multiple stakeholders, fostering a shared understanding of risks and promoting coordinated action. Ultimately, the proactive nature of the ABC method contributes to the long-term sustainability of cultural heritage assets.

The method has been successfully applied beyond museum contexts, including the evaluation of water-related risks at San Clemente Church in Albenga, Italy [40] and the management of natural and anthropogenic risks at Petra World Heritage Site in Jordan [41]. More recently, Adetunji and Daly [39] employed the ABC method to assess climate-related threats at five Nigerian cultural heritage sites.

3. Results and Discussion

3.1. Understanding the Context

The goal of this step is to develop a comprehensive understanding of all relevant aspects of the environment in which the heritage asset is located. This includes its sociocultural, political, legal, administrative, physical, and economic context.

The archaeological site under study is owned by the Rimini Chamber of Commerce [23]. According to Legislative Decree No. 42/2004, Article 1, Paragraph 4, the Chamber is classified as an autonomous functional entity governed by public law. As such, it is responsible for ensuring the preservation and public accessibility of its cultural assets during the course of its operations. The management and maintenance of the Chamber's movable and immovable cultural assets fall under the jurisdiction of the *Provveditorato* (a local administrative authority), and the financial resources allocated for the conservation of the archaeological site are drawn from the institution's operational budget, as outlined in its financial planning.

Currently closed to the public, access to the archaeological area is only occasionally granted, subject to approval by the Superintendence. The site can be reached via internal or external staircases or a lift, as displayed in Figure 4, and a metal boardwalk allows visitors to navigate across the various stratigraphic levels of the archaeological remains as shown in Figure 5a. The space is equipped with a manipulable air recirculation system (Figure 5a), and lighting is provided by a halogen lighting system (Figure 5a,b), as well as by sections of glass flooring in the waiting room above, which allow natural light to filter through from the skylight (Figure 5c).

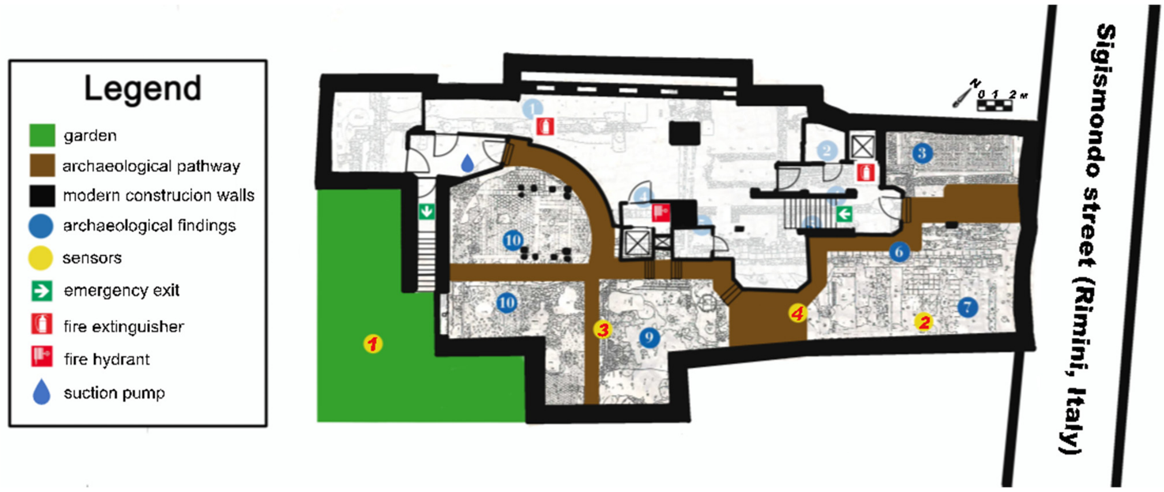


Figure 4. Visualization of the archaeological site in the underground floor of the Chamber of Commerce (Rimini).

Figure 5. Photos taken inside the archaeological site and inside the Rimini Chamber of Commerce: (**a**) late Imperial Era mosaic. On the right is the metal boardwalk and at its end is a portion of the air circulating system. Shown are the halogen lighting system and portion of the ceiling glass; (**b**) large room with apse and opus sectile floor of late antiquity period illuminated by the halogen lighting system; (**c**) the glass floor in the waiting room on the ground floor of the Rimini Chamber of Commerce.

According to the basement's emergency plan, both the internal and external staircases function as escape routes. In addition, the area is equipped with two fire extinguishers, a fire hydrant, and smoke-detection sensors. The groundwater level is regulated by a suction pump installed in a room adjacent to the archaeological site as displayed in Figure 4.

Before proceeding to the next stage of the ABC Method, the specific portion of the archaeological area to be included in the risk-management process was defined. Figure 4 illustrates the sections of the site selected for risk assessment and value estimation. This delineation identifies the distinct excavation areas, enabling a more focused evaluation of their authenticity. Table 1 describes each area, including its dimensions, construction period, and corresponding references from the TESS database—the national platform for the digital cataloguing of ancient floors in Italy [42].

Table 1. Description of the numbered elements of the archaeological sites of Sigismund Street in Rimini.

N°	Element	M^2	Age	Link to TESS Database
3 *	Opus signinum	19.25	Republican age	https://tess.beniculturali.unipd.it/web/scheda/?recid=6419 (accessed on 15 July 2025)
6	Opus spicatum and sewer collector bricks	7.7	Imperial age	/
7	2 Cubicula made in opus sectile	8.43 and 9 (North)	Imperial age	https://tess.beniculturali.unipd.it/web/scheda/?recid=6421 (accessed on 15 July 2025)
8	Opus Caementicium with tessellated edge	15.75	Late Republican	https://tess.beniculturali.unipd.it/web/scheda/?recid=6423 (accessed on 15 July 2025)
9	Portion of opus sectile	0.6	Late antique	https://tess.beniculturali.unipd.it/web/scheda/?recid=10523 (accessed on 15 July 2025)
9	Mosaic with floral motifs	40.7	IV century A.D.	https://tess.beniculturali.unipd.it/web/scheda/?recid=6427 (accessed on 15 July 2025)
9	Cocciopesto	2.3	Late antique—Early medieval	/
10	Opus sectile	1.7	Late antique	/
10	Terracotta fragments and cocciopesto	33.4	Late antique	/
10	Portion of a mosaic	2.05	Imperial age (?)/IV century A.D.	/
10	Opus sectile of the apsidal chamber	23.27	Late anqtique	https://tess.beniculturali.unipd.it/web/scheda/?recid=6430 (accessed on 15 July 2025)
	Entire archaeological site	161.25	From republican to Early medieval	https://tess.beniculturali.unipd.it/web/ricerca/risultati-ricerca/?ricercalibera=via%20sigismondo%20rimini (accessed on 15 July 2025)

* All numbers in this column refer to the numbers present in Figure 3.

For risk management to be as effective as possible, it is essential to clearly define the objectives and scope, including the precise extent of the heritage asset under consideration—is it the entire archaeological site or only a specific portion? To minimize the risk of subjective choices and evaluations, incorporating the concept of authenticity can be beneficial. Authenticity helps reduce the potential for arbitrary decision-making by grounding assessments in culturally and historically significant values.

According to UNESCO [43] (pp. 79–95), authenticity refers to a heritage asset's ability to convey the significance of its cultural value. Van Balen [44] describes authenticity as a multi-layered concept used to acknowledge heritage significance. However, due to the relative and culturally contextual nature of authenticity, it is generally not feasible to apply a universal standard for authenticity assessments [45]. Instead, authenticity should be evaluated within the specific cultural and historical context of each site [46], drawing on the insights of experts from a range of scientific disciplines [45].

To assist in this complex evaluation, the Nara Grid—a checklist tool based on the Nara Document on Authenticity and published by ICOMOS [47,48]—offers a structured approach by documenting authenticity across several dimensions: *Form and Design*, *Material and Substance*, *Use and Function*, *Traditions and Techniques*, *Location and Setting*, and *Spirit and Feeling*.

The suitability of the Nara Grid for guiding the adaptive reuse of historic buildings has been explored in various studies [49–52] where it has served as a tool for making decisions that respect the integrity and originality of heritage structures. To reduce subjectivity in selecting the section of the heritage asset to which the risk management process should be applied, we assessed the scalability of the Nara Grid for the context of the hypogeum archaeological site on Sigismund Street (see Table 2a.)

Table 2. (a) The Nara Grid for the archaeological site of Sigismund Street. (b) Relative value of each aspect within their dimensions of the archaeological site of Sigismund Street.

(a)

Dimension → Aspects	**Artistic**	**Historic**	**Social**	**Scientific**
Form and Design	The opus signinum and the apsidal room in opus sectile are rare examples in the antique city of Rimini and in regional panorama. The remaining findings are examples of a fairly good workmanship.	Portion of city neighborhood with a stratigraphy dating from the Republican Age to the early Middle Ages. A useful material source for deepening historical knowledge of the Roman city of Rimini.	Late antique findings testify a presence of elites in the Rimini area.	The apsidal room in dichromatic opus sectile and the presence of the interrupted water channel are important pieces of evidence concerning the economic and social management of a public site in Late Antiquity.
Material and Substance	The building materials are not in a good state of preservation (conspicuous efflorescence, biological colonization), as well as the modern structures (concrete walls, frames, ventilation system and lights).	All the archaeological findings have undergone only one restoration intervention and sporadic maintenance. The building materials are almost entirely original.	X	Diagnostic analyses carried out on the mortars and on lithotypes of the floral-patterned mosaic have provided a fairly accurate idea of the execution technique for the historical period. Further research is needed for the other archaeological remains, their related materials, and execution technique.

Table 2. *Cont.*

(a)				
Dimension → Aspects	**Artistic**	**Historic**	**Social**	**Scientific**
Use and Function	The archaeological site that is not open to the public but can be visited after notification to the Superintendence and the *Provveditorato*. It is not accessible for people with mobility disabilities.	Discovered in 1995, the archaeological evidence has been kept in situ.	Rare visits by visitors over time.	Rare visits by academics over time.
Tradition, Technics, and Workmanship	The archaeological floors preserve their original subfloors. Many marble crustae in the opus sectile have been preserved.	The execution techniques and superfetation show the evolution of the portion of the neighborhood over the centuries.	X	The study of the execution techniques, combined with the stratigraphy, allowed a more accurate dating of the mosaics.
Location and Setting	The building at 28 Sigismund Street is not subject to cultural constraint.	The presence of the archaeological site was intended to be a part of the tourist path called "Rimini Underground."	The presence of the archaeological site complicates management of the property. Two accidents of leaking sludge from the Roman sewer line in connection with external contaminants have caused deep disruption to Chamber of Commerce staff.	X
Spirit and Feelings	The site shows valuable examples of Roman workmanship and other lesser-known evidence. With proper explanation, the site could be attractive to visitors.	The archaeological site has been helpful in corroborating some theses about the presence of high-ranking elites during the Late Antique period in Rimini.	It could give back a glimpse of the historical evolution of the city of Rimini, although its lack of usability means that the site remains semi-unknown.	X

(b)

Value Dimension/Aspect *	**Artistic Value Points**	**Historic Value Points**	**Social Value Points**	**Scientific Value Points**	**All Points**	**Aspect as % of the Group ****
Form and Design	5 × 27	15 × 9	1 × 27	10 × 27	567	567/3187 = 18%
Material and Substance	5 × 1	15 × 81	1 × 0	10 × 27	1490	1490/3187 = 47%
Use and Function	5 × 3	15 × 3	1 × 3	10 × 0	63	63/3187 = 2.2%
Tradition, Technics and Workmanship	5 × 81	15 × 27	1 × 0	10 × 9	900	900/3187 = 28%
Location and Setting	5 × 0	15 × 1	1 × 1	10 × 0	16	16/3187 = 0.1%
Spirit and Feelings	5 × 3	15 × 9	1 × 1	10 × 0	151	151/3187 = 4.7%
Total					3187	100%

* Weights were selected using four incremental steps of +5 (i.e., 1, 5, 10, 15) for the contributing dimensions based on their relative importance: *Artistic = 5*, *Historic = 15*, *Social = 1*, and *Scientific = 10*. The ratio scale of six steps (3^n con n = 0–6), increasing by a factor of three, to score the "degree of occurrence" of each Nara Grid aspect (*Form and Design*, *Material and Substance*, *Use and Function*, *Traditions, Techniques and Workmanship*, *Location and Setting*, *Spirit and Feeling*). ** Relative percentage of each aspect: (all points/total) × 100.

The information collected in Table 2a is the result of historiographical studies of the archaeological context of Rimini, historical–artistic comparisons carried out with contemporary flooring, study of the execution techniques, the restorations carried out, the forms of alteration found, and the interviews carried out with the staff of the *Provveditorato* in charge of the protection and management of the archaeological site. Furthermore, with the examination of archival data, the conservative history and the modifications that have taken place could be reconstructed, enriching the data set collected from the investigations.

Subsequently, we adapted the Nara Grid's aspects and dimensions within the ABC Method framework to construct a value pie—a tool used to represent the multiple contributing values assigned to each element of the method [17] (pp. 53–56).

In Michalski and Pedersoli's original framework [17] (p. 55, Table 3), the social dimension is not included as a contributing value. Therefore, we incorporated it into our analysis. We assigned weights to the contributing dimensions based on their relative importance: *Artistic = 5*, *Historic = 15*, *Social = 1*, and *Scientific = 10*. These weights were selected using four incremental steps of +5 (i.e., 1, 5, 10, 15), in line with the methodology proposed by Michalski and Pedersoli [17] (p. 55, Table 3).

Table 3. Table of the resulting 10 agents of deterioration and loss.

Risk Occurrence → 10 Agents	Rare Events (<Than 1 per 100 Yrs.)	Common Events (>Than 1 per 100 Yrs.)	Cumulative Processes
Physical forces	Medium magnitude earthquake (fractures, cracks, deformations, collapse of the building above the archaeological site).	Walking and movement of equipment during maintenance and installation of systems or sensors. Operators and tools are positioned on archaeological floors (even if protected by sheets in some cases).	Damage due to impacts by occasional visitors. Dirt carried by visitors and people entering the archaeological site. Lack of a maintenance and cleaning plan for the archaeological site areas.
Thieves and vandals	/	/	/
Fire	Short circuit in the electrical system. Failure in the operation of fire-fighting devices. Risk of a forest fire spreading to neighboring areas.	/	/
Water	Use of the hydrant in case of fire.	Breakage or malfunction of the groundwater suction pump system and flooding of the archaeological site. Flooding of the basement due to extreme weather events of meteoric rains.	Efflorescence cycles in the winter months with the indoor RH decrease.
Pests	/	Presence of actinomycetes, algae, and fungi if no biocide treatments are applied.	Rapid proliferation (occurred in 5 spring-summer months with the presence of one or more operators during the proliferation period) of biological colonization one year after treatment. Presence of cobwebs and insects.
Pollutants	/	Leakage of BOD/5 liquids, ammonia NH3, and oily substances from the Roman sewer pipe probably connected to the modern sewer system and communicating with other compromised pipes or tanks.	General high concentration of CO_2, especially when people are present inside the archaeological site.

Table 3. *Cont.*

Risk Occurrence → 10 Agents	Rare Events (<Than 1 per 100 Yrs.)	Common Events (>Than 1 per 100 Yrs.)	Cumulative Processes
Light, UV, IR	/	/	Excessive lighting (IR and UV) coming from the glass hatch and from the installed halogen spotlights.
Incorrect temperature	/	/	Significant variations in temperature in a short period of time due to the switching on of the air recirculation system and to the frequentation of the archaeological site by people.
Incorrect RH	/	/	Relative humidity observed in the long term (annual) presents significant and dangerous excursions favoring the proliferation of efflorescence during the winter periods. Humidity rate far from the conditions of well-being of the stored materials and for the users. Incorrect handling of the air recirculation system triggers significant imbalances in the short term that trigger efflorescence phenomena.
Dissociation	/	Poor economic resources for maintenance, installation of additional UV lamps and replacement of the old ones, UV and IR shielding of the trapdoor and replacement of the lighting system, and restoration and maintenance operations of the entire archaeological area. Loss of the cases containing the erratic tiles of the geometric mosaic with floral motifs classified according to the area of discovery. Loss of the paper labels indicating the area of discovery of the erratic tiles. Loss of the paper material of the private archive present in single copy.	/

The weights assigned to each dimension are based on the same information used to compile Table 2a.

Following Michalski and Pedersoli [17] (p. 55, Table 4), we then applied a ratio scale to score the "degree of occurrence" of each Nara Grid aspect (*Form and Design*, *Material and Substance*, *Use and Function*, *Traditions, Techniques and Workmanship*, *Location and Setting*, *Spirit and Feeling*) [47]. This ratio scale consists of six steps, increasing by a factor of three, as outlined in Michalski and Pedersoli's work.

Table 4. List of risk sentences.

Agents of Risks	Sentences
Physical forces	**1.** An earthquake of moderate magnitude (Richter scale 5.0–5.9) will fracture the floors of the archaeological site and the building's structures, making the basement unusable; **2.** The buildings built up to 2003 without seismic regulations near the Chamber of Commerce (that could be untouched) will collapse following an earthquake of moderate magnitude (Richter scale 5.0–5.9). During an earthquake there will be many displaced people in the neighborhood where the archaeological site is located and the operations to secure the archaeological site will be neglected in order to provide priority assistance to civilians; **3.** A very strong earthquake of high magnitude (Richter scale 6.0–7.9) will cause very serious structural damage to the building above and some portions will fall onto the archaeological site, causing serious damage to the floors. It will also break the suction-pump mechanism and the archaeological site will flood;
Breakages and hits	**4.** Operators involved in the maintenance or installation of equipment or systems will place their tools or let them fall, damaging portions of the floors and structures; **5.** Visitors will cause damage by hitting into the surfaces and marginal floors of the walking path;
Thieves and vandals	/
Fire	**6.** A fire in the near XXV April park (Rimini, Italy) will spread next to the Chamber of Commerce building, making the basement inaccessible until the fire is extinguished; **7.** A short circuit in the electrical panel will cause a fire, forming stains and causing mechanical damage due to the collapse of plaster and high structures on the archaeological floors; **8.** The fire extinguishers used to put out the fire will stain the pavements and archaeological structures;
Water	**9.** The fire hydrant located halfway through the archaeological site will wet the ancient pavements, triggering degradation phenomena such as efflorescence and mechanical damage to the fragile materials hit by the jet of the hydrant; **10.** Between 2010 and 2039 the site will flood due to the increase 1.2 times per year in rainy periods of more than five consecutive days and due to precipitation greater than 200 mm per day more frequent than 6–13 times per year compared to the recent past (1961–1990); **11.** Between 2070 and 2099, the site will flood due to rarer but extremely violent phenomena; **12**. The pumps will become damaged or break, causing water and pollutants to rise up, flooding and dirtying the archaeological site;
Pests	**13**. After more than a year and six months from the last biocide treatment, if not repeated, biological colonization will progress quickly in the summer months until it reaches its ecological maximum, with the reappearance of cyanobacteria, algae, actinomycetes, and fungi. One year after the last treatment carried out in spring, cyanobacteria and algae will form on the areas exposed to natural and artificial light; **14**. The lack of a scheduled cleaning plan of the walkway portions will contribute to the proliferation of biodeterioration agents, insects, cobwebs, and to the accumulation of dirt on the findings;
Pollutants	**15.** Substances will infiltrate from the bordering wall and will make the excavation dirty; **16**. Water from the sewer pipe along with ammonia, BOD/5, and hydrocarbon substances will flood the archaeological site, dirtying it; **17**. The high concentration of CO_2 will cause discomfort to visitors and operators;
Light, UV, IR	**18.** The lighting system and the unscreened natural light coming from the glass ceiling will cause thermal inhomogeneities on the surfaces, favoring biological colonization; **19**. UV lamps not replaced periodically and not lowered in proximity to the area colonized by the microflora will lose their effectiveness as physical eradicators of biological colonization;

Table 4. *Cont.*

Agents of Risks	Sentences
Incorrect temperature and RH	**20.** During the winter months, salt crystallization will occur due to a decrease in internal relative humidity caused by the manipulation of the ventilation system;
Dissociation	**21**. The lack of written management guidelines and a scheduled maintenance plan for the findings will increase the degradation processes currently underway. The information acquired may be lost if there are not indicated responsibilities, action to be taken, and guidelines; **22**. Lack of funding will prevent the replacement of the lighting system, the air recirculation system, the UV lamps and the installation of new ones, and the shielding of the glass hatch from UV and IR rays; **23**. Lack of funding will prevent the restoration of the remaining surfaces of the archaeological site and the scheduled maintenance of the archaeological site; **24**. The plastic bags containing the erratic tiles and the paper tags with the information regarding the finding place of the tiles will be lost because the place for their storage and conservation has not been defined.

Table 2b presents the calculated values for each tangible and intangible aspect of the archaeological site on Sigismund Street, based on the weighted value assessments derived from the ABC Method.

The authenticity of the archaeological site is primarily defined by the original materials that have been preserved, as illustrated in the value pie in Figure 6. These materials are crucial for understanding historical floor construction techniques and the transformations of Rimini's urban fabric over time, shaped by socio-economic developments.

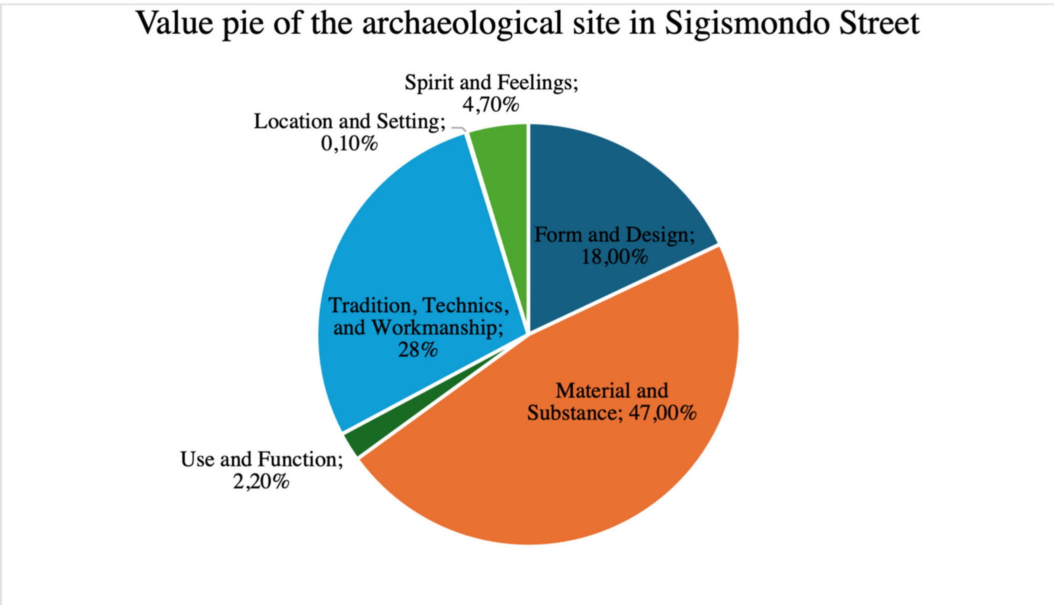
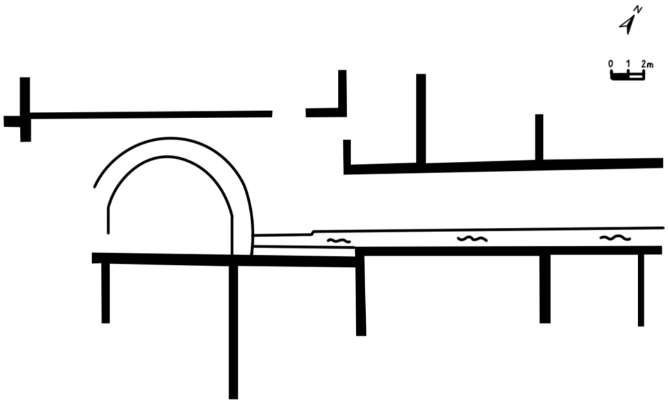


Figure 6. Value pie of the archaeological site in Sigismund Street.

Among the most significant elements are the stratified layers of geometric mosaic with floral motifs and the section of opus sectile superimposed upon it, as shown in Figure 7a, which together offer a representative cross-section of late Roman construction practices. Additionally, the presence of a sewer pipe intersected by the apsidal hall of a private building disrupts and fragments the urban block, symbolizing the assertion of aristocratic power over public space (Figure 7b) [20,22].

(a)



(b)

Figure 7. The most significant elements of the Sigismund archaeological site: (**a**) stratified layers of geometric mosaics with floral motifs and the section of late antique opus sectile superimposed upon them; (**b**) drawing of sewer duct with the structure interrupted by the apsidal hall, a private building [22] p. 16.

However, due to the site's underground (hypogean) nature, its accessibility is highly restricted. This limitation, along with its underrepresentation in both the tourism sector and scholarly discourse, renders other dimensions of value—such as intended use, location, and experiential aspects like spirit and feeling—largely irrelevant in this context.

3.2. Idenyfying Risks

The purpose of this phase of the ABC Method is to identify potential risk agents that could compromise the preservation of the heritage asset under study. To promote a more systematic and less subjective identification process, the method proposes a standard list of the so-called "10 Agents of Deterioration and Loss": physical forces, dissociation, incorrect relative humidity, incorrect temperature, light and UV radiation, pollutants, pests, water, fire, and vandalism. It is important to note that multiple risks can be associated with a single agent (e.g., water damage from flooding, pipe leaks, or rainwater infiltration into the building).

This phase also involves considering three types of risk occurrence: rare, common, and cumulative events.

The main objective is to prepare a list of risks and corresponding "risk summary sentences." These are clear, complete, forward-looking statements that identify the agent of deterioration, describe the likely adverse event, and specify which part(s) of the heritage asset are expected to be affected. The terminology must be precisely defined to ensure accurate risk recognition and to predict future harm—without focusing on damage that has already occurred.

The information used to identify risks at the hypogeum site and formulate the risk summary sentences is provided in Table 3. This data is drawn from a range of sources, including a microclimatic monitoring campaign analysis of past restoration reports and interventions, and scientific studies on microflora and observed degradation patterns (see Section 3.3. Analyzing Risks).

To better understand the specific territorial hazards, a multi-scalar approach was adopted—progressing from a broad, regional scale down to the detail of individual building components. Key resources that informed this assessment include: the ministerial cartography "Carta del Rischio" [53], the Civil Protection Plans of the Municipality of

Rimini [54], observation made in the past regarding preventative care [55] and research by Sabbioni et al. [56], which produced spatially explicit maps of potential long-term risks to cultural heritage.

The Carta del Rischio provides tools for assessing a wide range of risk factors—such as landslides, floods, earthquakes, volcanic activity, air pollution, and aerosol concentrations—in relation to different heritage types. It integrates environmental-hazard data produced by national institutions such as the ISPRA (Italian Institute for Environmental Protection and Research) [57] and the INGV (National Institute of Geophysics and Volcanology) [58], including seismic zoning and hydrogeological risk assessments [59].

By comparing data from the national cartographic system with the Rimini Civil Protection Plans—specifically tailored to the historic city center—a targeted evaluation of hazards was carried out. These municipal plans, mandated by Italian law, define responsibilities, procedures, and available resources for emergency management and public safety. Their integration into the risk analysis enabled a more detailed and context-specific understanding of current threats.

In the context of a hypogeal archaeological site, the mapping of Rimini's primary and secondary sewer networks was particularly useful in evaluating the potential interaction between modern infrastructure and the buried remains.

Finally, the possibility of theft and vandalism was not considered in this case study, as the site is located underground and is accessible only through private, restricted entry. It is important to reiterate that damage or loss of value occurs only when a heritage asset is both susceptible to and exposed to a risk agent.

3.3. Analyzing Risks

The goal of this step is to gain a deeper understanding of each risk identified in the previous phase. Simply identifying the risks that threaten the heritage asset is not sufficient for effective management. To prioritize these risks appropriately, it is essential to determine how significant each one is. For every risk, both the likelihood of occurrence and the expected impact must be estimated—the latter being expressed in terms of the anticipated loss of value to the heritage asset.

By quantifying the frequency (or rate) of occurrence and the expected value loss for each risk, the ABC Method employs numerical scales to calculate, compare, and clearly communicate the magnitude of risk.

- Component A represents the frequency of the damaging event or the rate of occurrence of a harmful process;
- Components B and C, when combined, represent the expected degree of value loss to the heritage asset.

Together, these three components—A, B, and C—define the overall magnitude of each risk.

The risk summary sentences developed in the previous risk identification phase (Table 4) served as the foundation for evaluating the ABC components. These sentences are grouped according to the 10 standard agents of deterioration.

Vandalism was excluded from consideration, as the site is a restricted and enclosed environment with limited access. Temperature and relative humidity were considered jointly, given their interdependent effects on environmental stability.

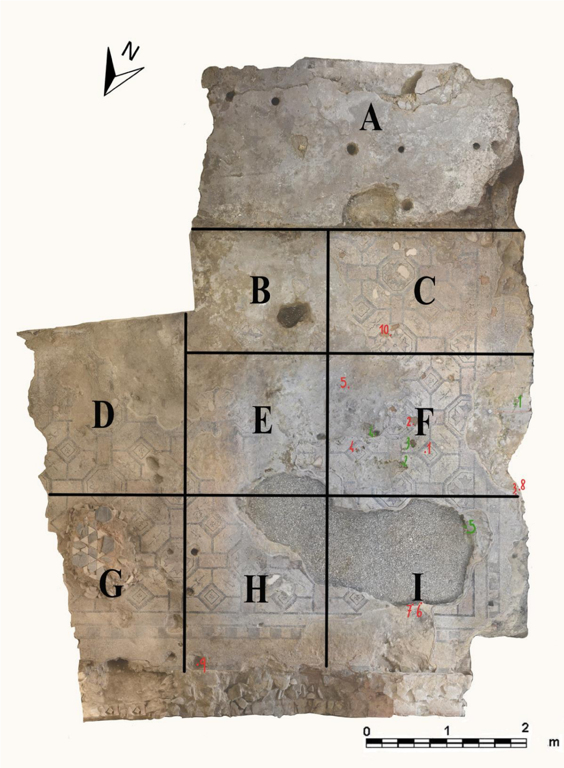
Twenty-four risk summary sentences were formulated based on the existing literature, research findings, and publicly available data. The aim was to establish a comprehensive framework that integrates both predictive analysis and empirical risk identification developed over time. Assessments of high- and medium-magnitude earthquake risks are informed by publications from the INGV [58] and historical seismic events documented in the Rimini area. In 2003, the municipality of Rimini was officially designated as a seismic zone, prompting the enforcement of anti-seismic building regulations for new constructions. According to the Civil Protection's seismic risk plan, the area is classified as high-risk, with potential impacts estimated in terms of displaced population figures [54]. Although no damage related to seismic activity triggered by visitors or staff has been recorded in the archives, hypothetical scenarios have been developed, particularly concerning the site's narrow walkways. Fire scenarios were considered both for external sources (e.g., proximity to Parco XXV Aprile) [54] and internal causes such as electrical malfunctions. These scenarios were evaluated despite the presence of certified fire protection equipment and regular inspections of the electrical panel [55]. Flood risk scenarios were formulated using data from the ISPRA's Carta del Rischio [53,57], municipal Civil Protection plans [54], climatic vulnerability maps forecasting weather-related events [56], and reports on the two major floods that affected Romagna in May 2023 [60–63]. Notably, the archaeological site remained unaffected, due to the floor's gradient, which allowed efficient drainage of water through a hatch equipped with a suction pump and from the internal courtyard of the Chamber of Commerce toward the adjacent archive. A risk scenario involving failure of the suction pump was also included, based on two past incidents recorded in historical documentation [55], despite the equipment undergoing routine annual maintenance. Risks related to biological agents were assessed through biological analyses and by monitoring the effectiveness of biocidal treatments over a one-year period. Prior to the 2023 conservation intervention, the archaeological site beneath the Chamber of Commerce of Rimini showed extensive degradation phenomena, including salt efflorescence, biological patinas, incoherent surface deposits, and structural losses. Scientific analyses were carried out to investigate the biological and inorganic forms of alteration. Biological analysis identified filamentous diatoms (such as *Fragilaria* sp.), and cyanobacteria, with specific reference to *Aphanocapsa* sp., suggesting recolonization following the biocidal treatment (Figure 8). XRD, TG-DTA, and SEM-EDS analyses confirmed calcium sulfate dihydrate (gypsum) as the primary efflorescence compound, with chlorides and nitrates inferred from sustained thermal weight loss above 800 °C.

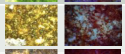
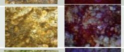
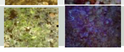
The absence of a scheduled cleaning and maintenance plan at the archaeological site fosters biological colonization and the accumulation of debris on archaeological materials. Two severe leakage incidents from the ancient Roman sewer system—likely linked to modern pipelines—are documented in the pollutant-related literature [55]. As such, the Civil Protection plan also served as a basis for analyzing the conditions of both primary and secondary sewer systems [54].

Risk evaluations concerning light exposure, thermohygrometric parameters, and carbon-dioxide concentration were developed through monitoring of indoor environmental conditions at the archaeological site, and through examination of display fixtures and furniture.

The environmental conditions of the archaeological site beneath the Rimini Chamber of Commerce have been critical since the first restoration works in 1999, as documented in reports by the Superintendency and CNR-ISAC researchers [64–70].

The interpretation of the monitored parameters confirmed that external climatic conditions, the behavior of the underlying groundwater aquifer, the operation of the air recirculation system, and human presence within the site all significantly influence the indoor microclimate of the archaeological area. As shown in Figure 9, the relative humidity trend for sensor UR3 exhibits more pronounced fluctuations than UR2, with both datasets showing substantial daily variation—up to 20 percentage points—between mid-January and late February, and again from early April to early May.



Zone	N° sample	Description	50X Vis/UV	Characterization
F	1CCBIO	Green patina		Probably cyanobacteria *Aphanocaspa*
F	2CCBIO	Green and dark brown patina		Probably cyanobacteria *Aphanocaspa*
F	3CCBIO	Green and dark brown patina		filamentous cyanobacteria
F	4CCBIO	Green and dark brown patina		Diatoms probably *Fragilaria* sp.
I	5CCBIO	Green patina on humid soil		Microalgae and diatoms

Zone	N° sample	Description	Analysis made	Characterization
F	1CCRN	Coherent deposit placed above the tessellate;	XRD, TGA-DTA	In the sample there is a high level of calcite (xxxxx) and a small amount of gypsum (xx). Coherent deposit consisting of crystallization water, calcite 66% of the sample, gypsum 5%, organic matter;
F	2CCRN	Half red tile with very sticky grey scale;	SEM	Calcium peak followed by carbon, oxygen, silicon, aluminum, sulfur and magnesium. Phosphorus peaks at the grey patina. Origin of bone waste and subsequent burial;
F	3CCRN	Probably burnt tile with white smear on top taken from area near the perimeter containment edge of the room;	XRD	The presence of calcite (xxxx) and a small amount of gypsum (xx) is detected in the sample;
F	4CCRN	black card with calcareous (probable) scale along the perimeter of the card taken by small gap;	TGA-DTA	Air behavior mortar. content in calcite 79% of the sample;
F	5CCRN	Layer 4 mortar having a uniform grey film of which the stratigraphy is well legible;	XRD, TGA-DTA	In the sample there is a very abundant quantity of calcite (xxxxx), presence of quartz (xx) and low presence of gypsum (x). Mortar hydraulic behavior. water crystallization, calcite 48% of the sample, gypsum 6%;

Figure 8. Image of the sample location (**on the left**) and the two summaries' description (**on the right**) of the analysis made for the biological patina (**green table**) and for the inorganic alteration forms (**orange table**).

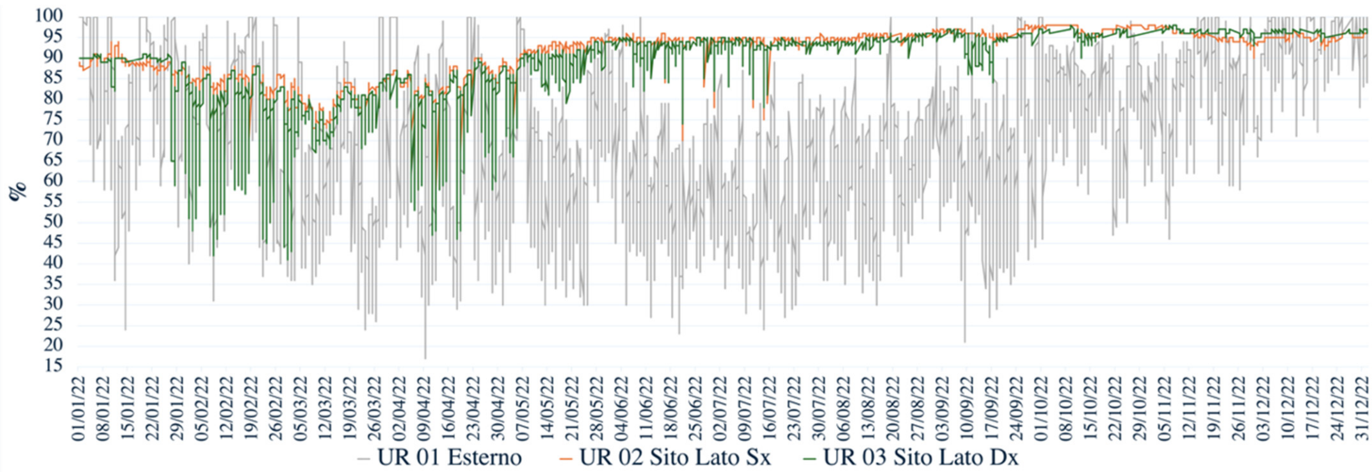


Figure 9. Relative humidity value trends (%) of 2022 year. UR2 internal RH left side (orange line), UR3 internal RH right side (green line), UR1 external RH (grey line).

During winter, relative humidity ranges from approximately 45% to 87%. Despite the lighting system being turned off during these periods—as confirmed by the illuminance data in Figure 10—ambient temperature variations persisted, indicating that lighting alone does not fully account for thermal changes. Notably, internal relative humidity during winter closely follows external humidity trends—particularly from early March to early April—suggesting a strong correlation.

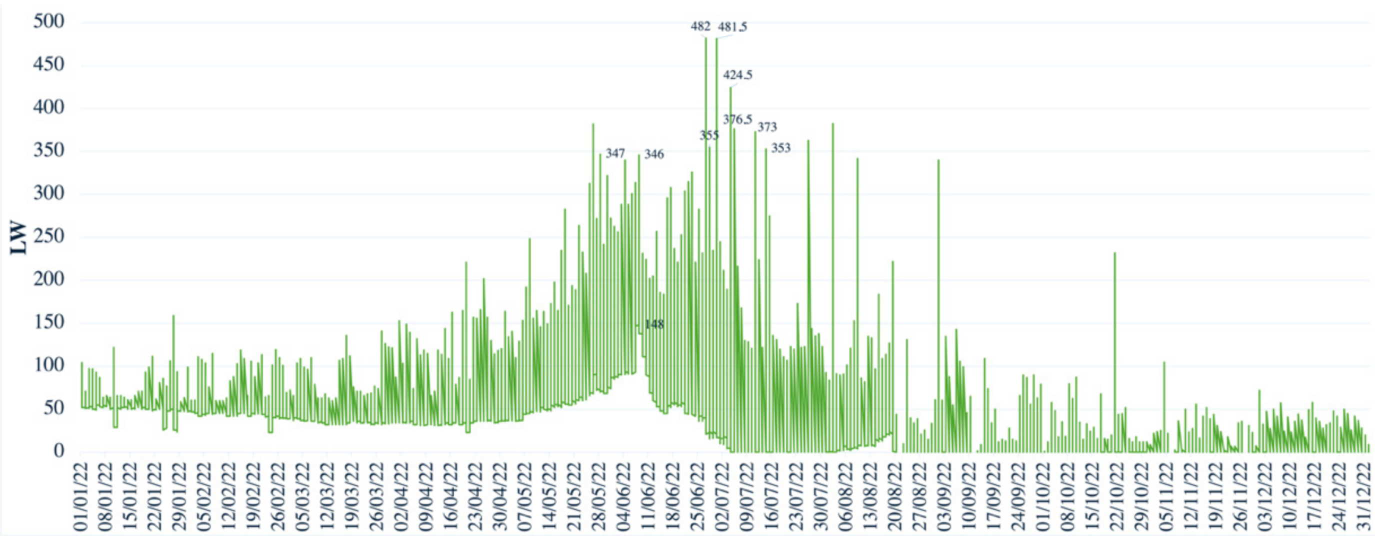


Figure 10. Illuminance value trends (lux). The sensor is located down the big glass ceiling near to HR UR3 left side sensor.

One hypothesis to explain these marked internal humidity fluctuations is the influence of the underlying aquifer. During winter, the water table is higher and more saturated than in summer, increasing capillary rise and moisture transfer to the archaeological structures above. Another contributing factor is the activation of the air recirculation system during the winter months. In January (Figure 11a), internal humidity curves (green and blue lines) show two distinct periods of imbalance, around 11–13 January and at the end of the month. In February (Figure 11b), relative humidity remains irregular, a pattern that continues through April (Figure 11c). Here, internal humidity levels appear to stabilize every weekend. This regular weekly pattern (Figure 11d) indicates that microclimatic fluctuations correlate with the activation of the air recirculation system. For instance, from Thursday, 31 March to Monday, 4 April, internal parameters remain stable; from Tuesday, 5 April, however, the curves become erratic and begin to mirror the external humidity trend (red line). This suggests that the air handling system disrupts the otherwise stable microclimatic conditions naturally maintained in the subterranean environment. Under such conditions—specifically, when the air recirculation system is active—evaporation processes may be triggered by sudden drops in relative humidity. This promotes the capillary rise of groundwater, carrying dissolved salts into contact with archaeological remains and surrounding cementitious materials. The result is the formation of visible efflorescence on mosaic surfaces, as documented in archival photographs and supported by salt crystallization data [71] (p. 189).

Another parameter that highlights the inadequacy of the existing air recirculation system is the carbon-dioxide concentration. In 2022 (Figure 12), CO_2 levels ranged from a minimum of 550 ppm to a peak of 1000 ppm. Between April and mid-August, the concentration remained relatively stable, fluctuating between 650 and 700 ppm. From mid-August to the end of December, it averaged between 760 and 820 ppm, showing greater variability. Notable peaks occurred on construction days—particularly on 26 May, the first day of restoration work—when CO_2 levels spiked to 1000 ppm due to the presence of six individuals working behind closed doors for approximately six hours. In the subsequent days, the door to the inner courtyard was kept open to allow minimal air exchange, which prevented similar peaks from recurring. These data underscore the ineffectiveness of the current air recirculation system, which is essentially non-operational. Monitoring CO_2 levels is particularly relevant in the context of potential musealization, as this parameter directly impacts the comfort and air quality experienced by future visitors, as well as by staff engaged in maintenance, restoration, or educational activities.

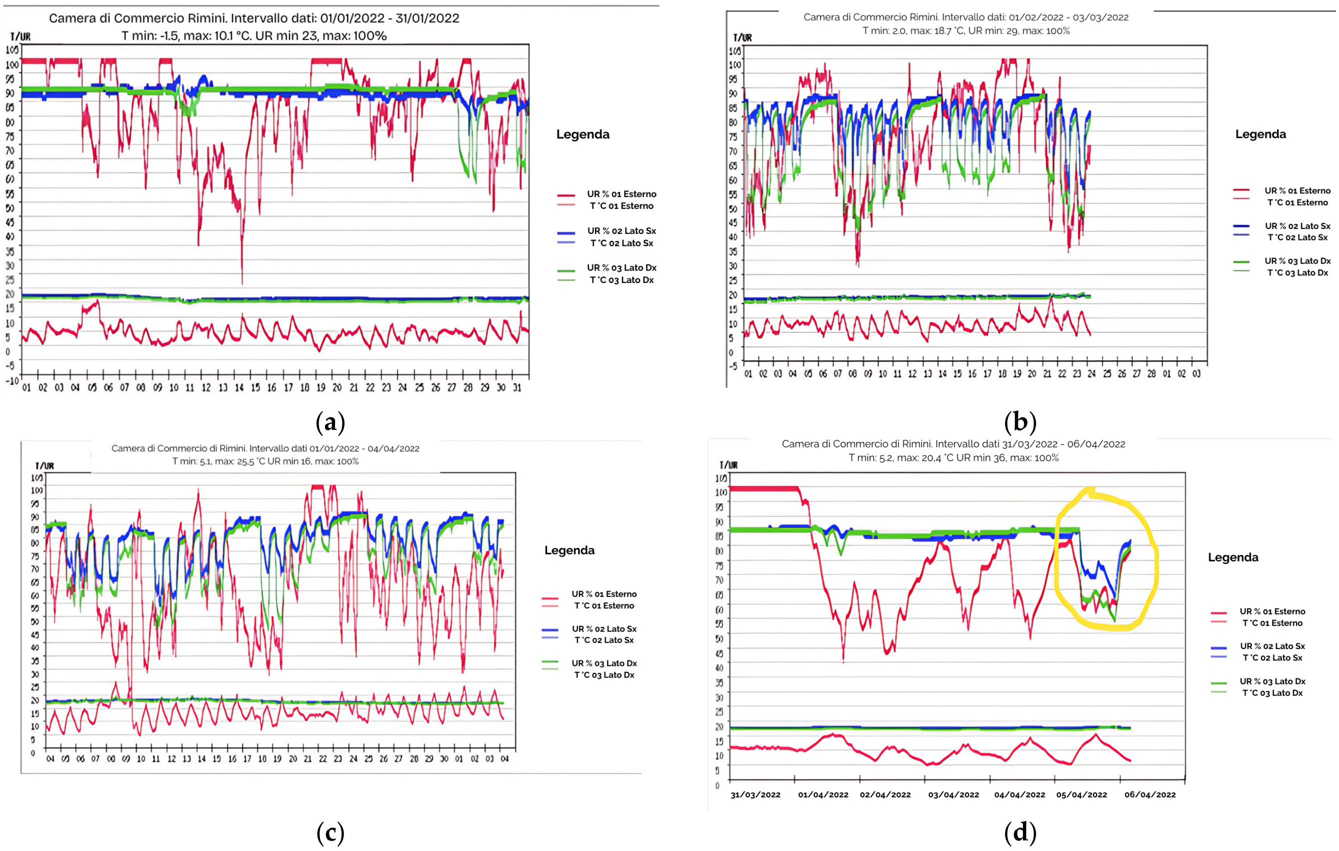


Figure 11. (**a**) Internal and external relative humidity and temperature value trends from 1 January 2022 to 31 January 2022; (**b**) internal and external relative humidity and temperature value trends from 1 February 2022 to 3 March 2022; (**c**) internal and external relative humidity and temperature value trends from 4 April 2022 to 4 May 2022; (**d**) internal and external relative humidity and temperature value trends from 31 March 2022 to 6 April 2022.

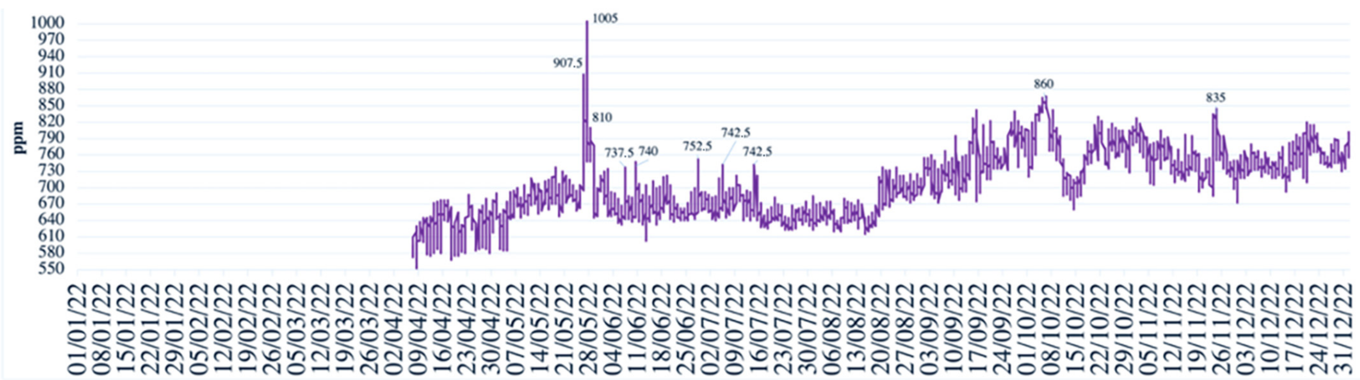


Figure 12. Trend in the rate of carbon-dioxide concentration during 2022 (ppm).

Finally, risks related to dissociation were identified based on research findings that highlight the absence of written conservation guidelines, insufficient planning of conservation resources, and the ongoing challenge of finding a suitable location to safeguard mosaic fragments awaiting restoration.

An example of risk-magnitude calculation for each risk sentence is provided in Table 5. Sentence #10, which concerns flooding events, was selected to illustrate how predictions from the literature—combined with territorial flood hazard assessments—have taken a significantly more critical tone following the two major flood events. These events prompted a reassessment of the site's vulnerabilities and underscored an urgency for safety measures that may have previously been underestimated.

Table 5. Summary of the risk analysis.

Deterioration Agent	Water
Risk name	Flooding of the archaeological site
Sentence of risk	*Between 2010 and 2039 the site will flood due to the increase 1.2 times per year in rainy periods of more than five consecutive days and due to precipitation greater than 200 mm per day more frequent than 6–13 times per year compared to the recent past (1961–1990), sentence 10*
Data	Number of recorded events: 1 (16 May 2023) flooding of the archive near to the archaeological site of the Chamber of Commerce Period in years: 28 (1996 to 2024)
Scale A: Frequency or rate	Between 2010 and 2039, similar phenomena will occur more frequently than in the recent past (1961–1990). Today we are at the level of 1 event recorded in 28 years from the excavation that did not involve directly the excavation but the locality near the archive. **A = 3 1/2**
Scale B: Loss of value to each affected item	Type of medium sensitive material: natural and artificial stone materials. Loss of value for each object: efflorescence, cracks, removal and displacement of fragile portions such as tiles, stone flakes. Estimated loss fraction for each item: 10–15% **Large loss of value for each affected object** **B = 4**
Scale C: Items affected	Number of floors in the archaeological site with greater risk of flooding (those near the door giving access to the pump room and the garden exit) = 4/12 Number of affected floors made up of the most susceptible materials when affected by an alluvial event: 3/4 Number of high value floors among those susceptible: 3/3 3/12 × 100 = 25% loss of high-value flooring 1/12 × 100 = 8.3% loss of medium-value flooring **A great loss of the total value of the collection** **C = 4 1/2**
A + B + C = M	**12**

The ABC component scores were assigned in accordance with the quantification tables of the ABC method.

After scoring the three components of each risk, the magnitude of risk (MR) was calculated by summing the values of components A, B, and C. Table 6 presents the assessment of risk magnitude, organized by severity. The formation of saline efflorescence on the mosaic floors emerged as the primary risk (MR = 13), followed by flooding of the archaeological site due to both current and future weather events (MR = 12), pump failure (MR = 12), and the absence of written management guidelines (MR = 12). These risks are classified as extreme priority due to their high estimated magnitudes.

Table 6. Magnitude of risk scale with implications.

Risk Sentence	MR	General Implications of the Range
20: development of efflorescence	13	Extreme priority
10: flooding of archaeological site due to climatic events on a near future	12	Extreme priority
11: flooding for violent phenomena in a far future	12	Extreme priority
12: flooding of the archaeological site due to pump malfunction	12	Extreme priority
21: lack of written management guidelines	12	Extreme priority
16: dirt caused by ammonia, BOD/5 and hydrocarbon from the sewer pipe	11	High priority
18: radiations that leads to thermal inhomogeneities	11	High priority
3: strong earthquake	11	High priority
15: infiltration of substances from the bordering wall	10.5	High priority
19: biocide efficacy of UV lamps thanks to the replacements of them	10	High priority
22: lack of funds for the replacements of fittings and facilities	10	High priority
1: moderate earthquake case 1	9	Medium priority
14: lack of scheduled cleaning plan	9	Medium priority
23: lack of funds for restoration of the remaining artifacts	8.5	Medium priority
2: moderate earthquake case 2	8	Medium priority
7: fire for a short circuit	8	Medium priority
9: wetting the site due to use of fire hydrants	8	Medium priority
13: lack of biocide treatment	7.5	Medium priority
4: hits by technical operators	6.5	Negligible priority
6: fire for external agents	6.5	Negligible priority
5: hits by visitors	6	Negligible priority
8: use of fire extinguishers on artifacts	6	Negligible priority
17: discomfort due to high concentration of CO2	5	Negligible priority
24: loss of bags containing erratic mosaic tiles	5	Negligible priority

3.4. Evaluating Risks

Once the magnitude of each risk is determined, the risks can be compared and prioritized. This allows decision-makers to identify which risks are acceptable and which must be addressed. The main criterion used for comparison is the magnitude of risk (MR). In the ABC Method, MR values are classified by priority level as follows [17]:

- Catastrophic ($13.5 < MR \leq 15$);
- Extreme ($13 < MR > 11.5$);
- High ($11 < MR > 9.5$);
- Medium ($9 < MR > 7.5$);
- Low ($7 < MR \geq 5$).

Figure 13 compares the MR values for each risk identified in the case study. The tornado chart visually represents the three components for each risk sentence, highlighting that saline efflorescence development is the top priority. This is attributed to multiple factors: the lack of an adequate HVAC system, the intentional manipulation of ventilation, the presence of bare soil, and the absence of both a maintenance schedule and access control for technical personnel. Addressing this issue as a priority may also help mitigate other risks, as many of the extreme-priority events are directly or indirectly linked to it.

The ABC method also accounts for uncertainty, as risk assessment is inherently probabilistic. In this case study, risk prioritization was adjusted to reflect the confidence level of estimates and the severity of risks. Re-evaluating MR for each risk sentence revealed that risks with cumulative frequencies—tracked by sensor data—had smaller calculation errors compared to those based on unpredictable weather events.

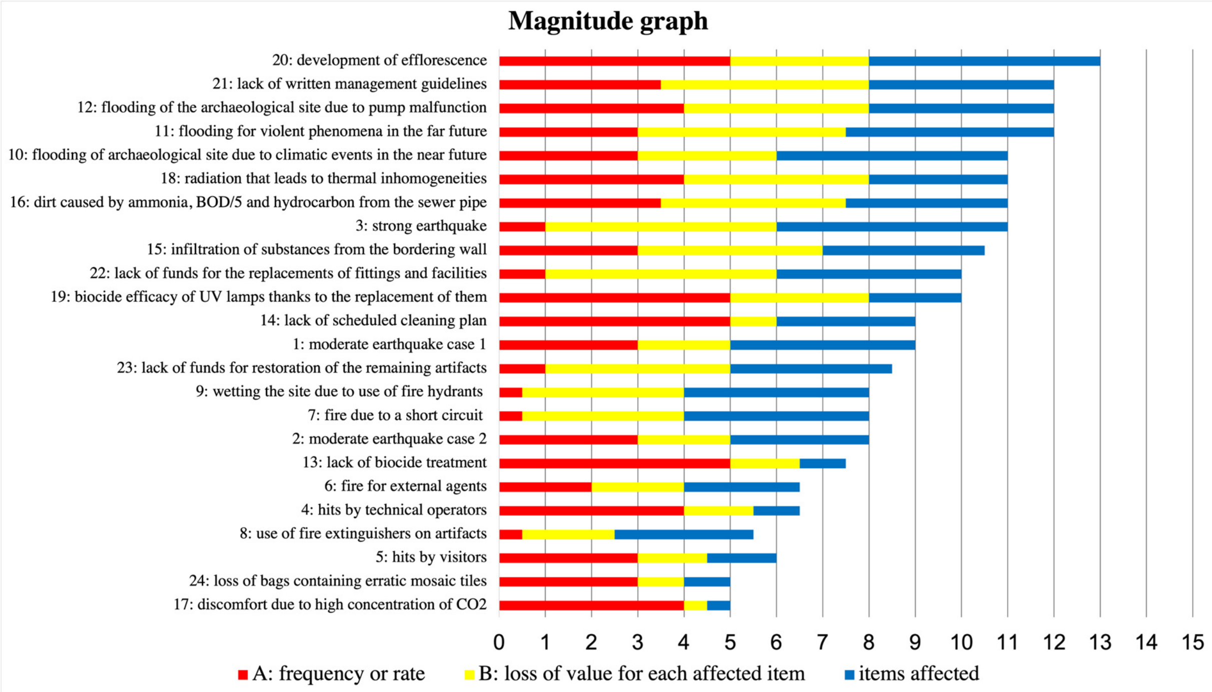


Figure 13. The magnitude graph or tornado graph.

Figure 14 categorizes risks into "high" and "low" priority based on a magnitude threshold of MR = 10 and an uncertainty value of 2, as recommended by Michalski and Pedersoli [17]. This allows clustering of risks with similar levels of uncertainty. The upper-left quadrant of the diagram identifies the most urgent risks—those with both high magnitude and high likelihood—targeted for immediate action.

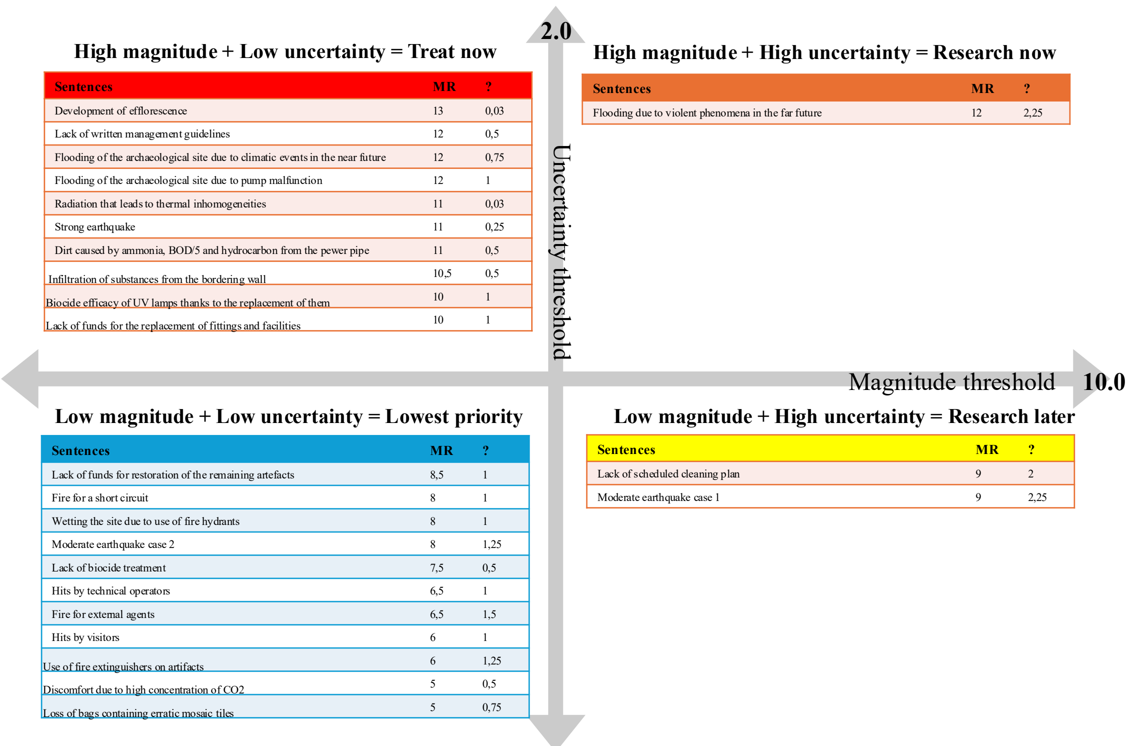


Figure 14. The magnitude of risks versus uncertainty table.

Uncertainty was estimated by evaluating each risk twice and calculating the absolute error as the difference between the two assessments. The first estimate served as the "true value," and the second as the "measured value," yielding Formula (1):

$$\textbf{Absolute Error} = |\textbf{Measured Value} - \textbf{True Value}| \quad (1)$$

Compared to Figure 13, the reordered priorities in Figure 14 place greater emphasis on risks such as the absence of written guidelines, which now surpass flood-related risks. This change reflects a reduced estimated probability and immediate consequences of extreme climate events, in contrast with the ongoing, well-documented lack of conservation planning that has significantly contributed to the site's current state.

The risk from saline efflorescence (MR = 13 ± 0.03) remains the highest priority, followed by the absence of a site-management strategy (MR = 12 ± 0.5), which includes gaps in personnel training, cleaning protocols, and infrastructure. No comprehensive management guidelines have ever been implemented—only sporadic actions responding to isolated issues such as sewage leaks or microclimate stabilization efforts (e.g., research by CNR ISAC in 2009 and 2014) [58,63].

Flood risk in the near term (MR = 12 ± 0.75) is assigned a higher level of certainty than long-term projections (MR = 12 ± 2.25), due to the inherent variability of future climate predictions. Pump malfunction risk (MR = 12 ± 1) also ranks highly, based on past failures [REF: CC archive], though the full extent of possible damage is unclear.

Light exposure (MR = 11 ± 0.03) is a significant environmental stressor, supported by both the literature [25,26,49] and illuminance monitoring data (see Section 3.3 Analyzing Risks). High-magnitude earthquakes (MR = 11 ± 0.25), although infrequent, could result in near-total site destruction, justifying their low uncertainty rating. Medium-magnitude earthquakes (Case 1: MR = 9 ± 2.25; Case 2: MR = 8 ± 1.25) occur more frequently but with less clarity on potential damage, resulting in greater uncertainty.

Two risks related to air pollutants (MR = 11 ± 0.5 and MR = 10.5 ± 0.5) are classified as high priority, with moderate uncertainty (see Section 3.3 Analyzing Risks). While some mitigation steps were initially taken, necessary follow-ups were not implemented [25,26,55], meaning the risks persist due to administrative inaction rather than environmental unpredictability.

The limited effectiveness of Wood's biocidal lamps (MR = 10 ± 1) is evident from historical photographs showing persistent microbial growth after their installation [22,55]. Finally, funding limitations (MR = 10 ± 1) pose significant risks in the event of large-scale emergencies. For smaller interventions, however, the Chamber of Commerce has consistently provided support (e.g., sensors, remediation services, and sewage panalysis) [22,55].

The most likely positive outcome of this research would be the drafting of detailed conservation guidelines, clearer assignment of responsibilities, and proposals for addressing the primary risk of efflorescence. These outputs would also support future research and financial investment in risk mitigation.

The ideal scenario would involve reducing all risks with MR > 10 and low uncertainty. Doing so would address the majority of threats, promote awareness, and establish a structured management approach with clearly defined responsibilities and formalized best practices. However, the main challenge lies in securing adequate funding and ensuring that stakeholders are both willing and able to commit the necessary time and effort.

The worst-case scenario would involve significant expenditure on medium-impact interventions requiring specialized personnel or continuous maintenance yet it yielding negligible conservation benefits. Alternatively, drafting guidelines that are ignored or left unimplemented would result in wasted resources and minimal improvement to site preservation.

3.5. Treating Risks

The final step in the risk-management cycle involves treating the identified risks. After assessing the risks, evaluating their magnitude, and determining which ones pose the highest priority to the heritage asset, effective measures can be proposed to eliminate or reduce these threats. The ABC method recommends addressing five distinct stages of control: avoid, block, detect, respond, and recover. These stages encompass both preventive and reactive strategies aimed at minimizing risks to heritage assets. Although prevention is generally more effective than reaction, sound risk management integrates both to achieve optimal results.

At this stage, and in line with the most likely scenario, a selection has been made to illustrate the treatment methodology for the two highest-priority risks with the greatest certainty of occurrence. This approach also accounts for the treatment of related secondary risks. Consequently, providing stakeholders with an initial list of urgent remedial actions is considered both appropriate and useful.

A stages-and-layers matrix is presented in Table 7. Although the layers (e.g., site, building, rooms) are primarily physical and geographically based, the matrix cells may also include intangible elements, such as organizational procedures and staffing structures.

Table 7. The layers and stages matrix.

Risk 1: Development of Efflorescence and *Risk* 2: Lack of Written Guidelines *					
Stages → Layers of Treatments	**Region:** Emilia–Romagna (Italy) **Local Superintendence**	**Site:** Rimini, Chamber of Commerce **Provveditorato**	**Building:** Basement of the Chamber of Commerce	**Room Furniture:** Walls, doors, pathway	**Engeneering Systems:** Sensors, light system, air circulating system
AVOID	*Avoid allowing more than a year to pass before carrying out the monitoring of parameters.* **Avoid opening doors without a proper reason.**	**Avoid turning on the actual air conditioning system.**	*Avoid unnecessary openings of the archaeological site. Avoiding tuning on light without a proper reason.*		*Prevent the interruptions of the sensors (check after power cuts if they are functioning).*
BLOCK		**Block the efflorescence phenomenon by arranging a yearly maintenance action. Block the occurrence of efflorescence with a new climatization system.**		**Block the passage of IR and UV radiations by using adhesive filtering panels.**	

Table 7. *Cont.*

Risk 1: Development of Efflorescence and *Risk 2*: Lack of Written Guidelines *					
DETECT	**Carry out half-yearly checks on the thermohygrometric trend recorded by the sensors and produce a summary report.** *Detect a responsible person for this.*	*Report the presence of people on the site in a dedicated register.*			
RESPOND	*Approve a maintenance plan.* *Approve the changes of furniture and facilities.* *Approve the cleaning plan.*	*Carry out a maintenance plan.* *Plan a cleaning schedule.*		**Need for thermal isolation of site access points.** **Purchase adhesive panels.**	
RECOVER	*Supervise, if necessary, maintenance interventions and review procedures.* *Observe the improvement of the action taken yearly.*	*Call a restoration team to carry out maintenance yearly.* **Use dry or a wrap efflorescence removal during maintenance actions.** **Find funds for the replacements of furniture and for shielding the site from the natural light.** **Find funds for a new climate system.** *Observe the improvement of the action taken yearly.*		*For the modern walls use a dehumidifier plaster due to the high and constant amount of moisture.* *Find funds for a system that could isolate the site access.*	**Install a new air-conditioning system.** *Replace the lighting system with a new one with LED light.* *Replace the UV lamps and move them closely to archaeological artifacts.*

* Related information on Risk 1 is shown in **bold** and related information on Risk 2 is shown in *italics*.

In Table 7, the two priority risks are distinguished by different text styles: bold for Risk 1 and italics for Risk 2. The stages avoid, block, detect, and respond are considered preventive actions, while recover is categorized as a treatment action.

Once all feasible measures to reduce the priority risks have been considered, the next step involves planning their implementation. This plan should include

- A realistic timetable (How long will the implementation take?);
- Measurable outcomes (What changes or improvements can be observed or quantified?);
- Clear roles and responsibilities (Who will be responsible for what actions?);
- The necessary resources (What equipment, materials, funding, and personnel will be required?).

The conclusions of the risk analysis are summarized, and a series of potential solutions is outlined in Table 8. The proposed options for addressing the priority risks—namely, the development of efflorescence and the absence of written guidelines—are discussed below.

The installation of a new, continuously operating ventilation system is the least effective of the proposed solutions when considering cost, sustainability, and long-term resolution. While technically effective, this option demands an invasive design and substantial financial resources for both implementation and maintenance. Moreover, it only addresses Risk 1 directly, whereas the alternative solutions also help mitigate related secondary risks.

Table 8. Table for comparing the advantages, disadvantages, and cost of risk-reduction options.

Specific risk and option →	**R. 1, option 1:** installation of a new ventilation system functioning h24	**R. 1, option 2:** Switch off the ventilation system and arrange a maintenance plan for the archaeological site (cleaning of artifacts and furniture) and monitoring of the parameters registered by the sensors at least every six months. No changes in the existing furniture/supplies	**R. 1, option 3:** Switch off the ventilation system insulate doors, use dehumidifier plaster for modern walls, replace the lighting system with LED lamps, replace biocidal UV lamps with new ones (and more), arrange a UV and infrared shielding of glass floor
MR of the specific risk	13 +/− 0.025	13 +/− 0.025	13 +/− 0.025
MR residual if option implemented	Significant reduction	Significant reduction	Very noticeable reduction
Reduction of other risks	no	Risks 21, 19, 14, 13	Risks 18, 19, 17
Option conflicts	Expensive, invasive solution. Need experts to design the project, estimate cost and the affirmative response from the Superintendence. Interruption of system can trigger serious damages. An expert is needed for maintenance of the system. Not healthy environment for humans (high and constant amount of moisture is needed). The growth of biological colonization will continue	Expensive, quite invasive solution. For monitoring thermohygrometric parameters evaluate using three options: the continuation of a contract with CNR-ISAC for report writing, call for an expert every six months or training of an employee in data reading. Need to call restoration company yearly (approved by the Superintendence). The growth of biological colonization will not continue	Expensive. Several specialists are needed to propose solutions and cost estimates to replace old equipment. It is necessary to have technical advice on the management of new facilities in order to have decision-making autonomy. Affirmative response needed from the Superintendence. The growth of biological colonization could not continue
Other benefits	Correct parameters for the hypogeum environment and stable parameters.	Resolute option Healthiness of the environment (both human and archaeological findings), increase awareness in dealing with issues and more decision-making autonomy during the years	Not too much invasive solution. Healthiness of the environment, sustainable solutions over time, low maintenance needed.

Table 8. *Cont.*

Feasibility	Yes, need of expert consultancy (architect, engineer, electrician, and Superintendence)	Yes, a cost estimate of the restored mosaic maintenance and for the monitoring of thermohygrometric parameters is provided by an expert. There is already the possibility of a collaboration contract between CNR-ISAC and the institution that owns the sensors	Absolutely yes, need expert option and cost estimation (architect, engineer, electrician, and Superintendence)
Sustainability	No, consistent use of electricity, possible difficulty in replacing damaged parts	Not properly. Need constant maintenance over the years, money, and use of products (biocides, demineralized water supporters, and consumables in large quantities)	Yes, low maintenance needed, improvements in energy efficiency, quite easy replacement of the fittings
Cash cost (estimate)	Presumably very high costs for the design of the project and the installation. Need an estimation cost made by an engineer	Approximately EUR 26,700 for the yearly maintenance of the mosaic (not the entire site). The price could be reduced if the institution buys large amounts of the consumable products used for the maintenance program. Dry removal with brushes could be a cheaper option to be made more frequently than the removal with wraps. EUR 870 for calling an expert for the monitoring of the parameters every time (EUR 1740 per year)	Presumably very high costs for the design of the project and the installation. Need an estimation cost made by an engineer and an architect
Other costs	Energy cost (system is turned on 24 h)	Maintenance costs for the other archaeological findings and the cleaning services (at least monthly)	Energy costs (the systems need to be turned on and off wisely)
Cost-effectiveness	Not properly, high costs of maintenance during the years (consider the replacement over a long time)	If the Institution acquires the products and learn how to make a report, the initial costs may be reduced significantly	Not high cost of maintenance, sustainable resolutions, the replacements could be quite easy
Creates new risks?	Yes: potential high damages if the system turns off/ is broken	Maintenance operations, if not performed wisely, can create new risks (biological colonization in new zones and groundwater contamination)	Not according to the current state of knowledge. Need to supervise thermohygrometric parameters and effectiveness over the time

Drawing on the restoration work performed on the mosaic floor with geometric motifs and the results of thermohygrometric monitoring, the second option was evaluated using the Restoration of Artistic Heritage (ARI) price list [72]. Purchasing maintenance materials in bulk and training Chamber of Commerce personnel to interpret recorded environmental data would enhance overall management awareness and reduce both initial training and ongoing maintenance costs. This option appears highly viable, particularly because it also contributes to resolving Risk 2 (lack of management guidelines).

From a perspective of cost-effectiveness, long-term sustainability, and the mitigation of multiple secondary risks, the third option—replacing outdated and unsuitable systems—emerges as the most strategic. Currently, salt removal and biocide treatments are carried out biannually; however, a more stable microclimatic environment, enabled by an improved ventilation system, would allow for longer intervals between maintenance cycles.

Supporting data for such an investment include recent microclimatic monitoring and comparisons with archived data [64,69]. This body of evidence establishes a theoretical foundation for estimating qualitative long-term savings relative to current cost projections.

In conclusion, simultaneous implementation of solutions 2 and 3 would likely produce positive spillover effects for the archaeological site. A combined strategy involving scheduled maintenance, documented through written procedures and upgrading key technical systems, could significantly enhance both the conservation and usability of the site.

4. Conclusions

This study demonstrates the application of the ABC Method for risk management and preventive conservation of hypogeal cultural heritage, using the archaeological site of Via Sigismondo—located beneath the Chamber of Commerce in Rimini—as a case study. To date, no prior application of this method to this site has been identified in the literature. As such, this research may serve as a precedent for similar contexts.

A further innovative contribution lies in the incorporation of the concept of authenticity, as articulated in the Nara Document on Authenticity, to evaluate the method's value. The use of the Nara Grid enabled a more objective assessment of decisions and the weighting of various dimensions and aspects related to the archaeological heritage, helping to mitigate the influence of personal judgment, subjective sensitivities, and stakeholder biases.

The integration of environmental monitoring, historical documentation, stakeholder engagement, and systematic analysis through the ABC framework proved effective in identifying, assessing, and prioritizing the site's diverse risks.

This methodology facilitated the formulation of a ranked list of priority actions. It provided cultural-heritage professionals with a structured approach to systematize research findings and establish a justified hierarchy of interventions.

The findings indicate that the most critical threats to the site include the formation of saline efflorescence, recurrent flooding, stemming from both infrastructural deficiencies and extreme weather events, and the absence of structured management guidelines. These risks collectively pose a significant threat to the physical integrity, authenticity, and long-term accessibility of the archaeological remains.

In response to these challenges, the study proposes practical and cost-effective mitigation strategies for the top-priority risks. It highlights the importance of implementing routine maintenance plans, enhancing environmental-control systems, and providing targeted staff training. The assessment suggests that specific interventions—such as upgrading infrastructure and introducing written conservation protocols for facility use, artefact maintenance, and cleaning schedules—can yield widespread protective benefits across multiple risk domains.

More broadly, this case study presents a scalable methodology adaptable to other hypogeal or vulnerable heritage contexts. It advocates for an integrated, multidisciplinary approach to cultural heritage conservation—one that combines scientific rigor with pragmatic planning and community engagement. By advancing the practical application of the

ABC Method in complex environments, the study offers a meaningful contribution to the fields of heritage preservation and risk management.

Author Contributions: Conceptualization, S.F., A.C. and M.V.; methodology, M.V.; resources, A.C. and M.V.; data curation, S.F., M.V. and A.C.; writing—original draft preparation, S.F. and A.C.; writing—review and editing, M.V. and S.F.; visualization, S.F.; supervision, M.V.; project administration, M.V.; funding acquisition, M.V. All authors have read and agreed to the published version of the manuscript.

Funding: The project is funded by the European Union—NextGenerationEU under the National Recovery and Resilience Plan (PNRR)—Mission 4 Education and research—Component 2 From research to business—Investment 1.3, Notice D.D. 341 of 15 March 2022, en: PE0000020—CUPJ33C22002850006, entitled: Cultural Heritage Active Innovation for Sustainable Society, duration until 28 February 2026.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to express their sincere gratitude to Michele Macchiarola, researcher at CNR-ISSMC in Faenza, for conducting the diagnostic analysis of the forms of alteration and the constituent materials of the polychrome mosaic floor with floral motifs. Their heartfelt thanks also go to Paola De Nuntiis, researcher at CNR-ISAC in Bologna, for her insightful observations and valuable guidance regarding the sensor data collected at the archaeological site. The authors are deeply grateful to Maria Cristina Carile for her expert advice on the archaeological research conducted in the Rimini area, particularly concerning the Late Antique phase of the city. Special thanks also go to Rossella Pistocchi for her interpretation and analysis of the biological samples recovered from the site. The authors extend their warmest thanks to the *Provveditorato* of the Chamber of Commerce of Rimini for granting access to their private archives and for allowing research activities to be conducted at the archaeological site. Finally, the authors wish to thank conservator Marco Santi, along with conservator Anna Caterino, for their invaluable guidance throughout the preparation of this work, and for fostering a productive collaboration with the Chamber of Commerce of Rimini, which made this project possible.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ARI	Association of Italian Restorers
ARPAE	Regional Agency for Prevention, Environment and Energy of Emilia–Romagna
CCI	Canadian Conservation Institute
CNR-ISAC	Italian National Research Council—Institute of Atmospheric Sciences and Climate
CNR-ISSMC	Italian National Research Council—Institute of Science and Technology for Ceramics
CO_2	Carbon dioxide
HR	Relative Humidity
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOMOS	International Council on Monuments and Sites
INGV	Italian National Institute of Geophysics and Volcanology
IR	Infrared Radiations
ISO	International Standard Operation
ISPRA	Italian Institute for Environmental Protection and Research
MDPI	Multidisciplinary Digital Publishing Institute
MR	Magnitude Risk
S.A.Bo	Archaeological Superintendence of Bologna

SEM-EDS	Scanning Electron Microscopy-energy Dispersive Spectroscopy
TESS	Computerized system for cataloguing ancient floor coverings
TG-DTA	Thermogravimetric Analysis-differential Thermal Analysis
UNESCO	United Nations Educational, Scientific and Cultural organization
UV	Ultraviolet Radiations
XRD	X-Ray Diffraction

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