heritage

MDPI

Article

Risk Assessment and Vulnerability Analysis of a Coastal Concrete Heritage Structure

Teresa Cunha Ferreira [1,*], Xavier Romão [2], Pedro Murilo Freitas [1] and Hugo Mendonça [3]

[1] CEAU, Faculty of Architecture, University of Porto, 4150-465 Porto, Portugal; pfreitas@arq.up.pt
[2] CONSTRUCT-LESE, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal; xnr@fe.up.pt
[3] Faculty of Architecture, University of Porto, 4150-465 Porto, Portugal
* Correspondence: tferreira@arq.up.pt

Abstract: This research focuses on the risk management of reinforced concrete heritage constructions in coastal environments, with an emphasis on preserving their cultural significance. It addresses a critical gap in existing risk-related research, since this type of heritage site is often overlooked in heritage conservation research. The proposed methodology offers a flexible framework that links natural and human-induced hazards with their impacts on key heritage values, enabling the development of appropriate mitigation and adaptation strategies and policies. Climate change-induced threats are also incorporated, allowing for more effective adaptation plans to safeguard concrete coastal heritage for future generations. The Ocean Swimming Pool in Matosinhos, Portugal, designed by the Pritzker Prize winner Álvaro Siza, serves as a pilot study to illustrate the practicality of the risk-based approach, considering its coastal location and exposure to various hazards. By using this case study, the research provides a roadmap for preserving and adapting heritage constructions in similar coastal settings. The integration of cultural values into risk management and conservation policies is a significant contribution of this research. It advocates for a proactive approach that considers the dynamic challenges posed by climate change while preserving the significance of cultural heritage. The adaptable nature of the proposed methodology allows for broader applications, potentially benefiting multiple heritage sites in coastal regions. Ultimately, this research calls for positive changes in risk management practices to ensure the preservation and longevity of culturally significant reinforced concrete heritage sites.

Keywords: vulnerability; climate change; cultural significance; modern heritage; concrete; coastal environment; conservation planning; Ocean Swimming Pool

check for updates

Citation: Cunha Ferreira, T.; Romão, X.; Freitas, P.M.; Mendonça, H. Risk Assessment and Vulnerability Analysis of a Coastal Concrete Heritage Structure. *Heritage* **2023**, *6*, 6153–6171. https://doi.org/10.3390/heritage6090323

Academic Editors: Ákos Török, Humberto Varum, Fernanda Prestileo and Vasilis Sarhosis

Received: 1 June 2023
Revised: 21 August 2023
Accepted: 28 August 2023
Published: 30 August 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Reinforced concrete constructions located in coastal environments, namely in intertidal and splash areas, are known to be vulnerable to a wide range of degradation phenomena [1–3]. Exposure to the ingress of chloride ions from seawater alone can cause steel corrosion in reinforced concrete, which can then lead to spalling of its surface [4]. Moreover, these constructions can be further exposed to damage resulting from coastal erosion or hydrometeorological events [5,6]. In addition, the increasing rate of phenomena related to climate change is introducing new challenges that can affect the vulnerability of these constructions. For example, aside from creating new threats such as sea level rise, climate change is also intensifying the occurrence of coastal erosion and extreme hydrometeorological phenomena [7–9]. Furthermore, for the particular case of reinforced concrete constructions, the rise of atmospheric CO_2 concentration and temperature are known to lead to an increase in concrete carbonation [10–13], which in turn leads to a non-negligible increase in carbonation-induced corrosion of steel reinforcement [14–16]. Overall, these several phenomena can lead to a number of issues that may affect the functionality, aesthetics, and durability of reinforced concrete constructions.

Anthropogenic hazards are another source of threat to construction in general. These hazards are related to human-induced actions or inactions that endanger constructions and can lead to devastating consequences if left unaddressed. Anthropogenic hazards can be grossly divided into intentional human activity that is malicious and has negative impacts, intentional human activity that is non-malicious, but that may have negative impacts, and non-intentional human activity that may have negative impacts. While the identification of some of these hazards is sometimes difficult, one of the key challenges for their inclusion in risk management processes is often related to the definition of their likelihood, since their occurrence cannot be predicted using probabilistic models based on the recurrence of these events.

When the construction exposed to the hazard is also considered culturally significant, additional features are also at risk due to the likely loss of integrity caused by the negative hazard impacts. In this context, modern architecture is particularly vulnerable to certain types of hazards given that, at the time of construction, the material and technological features that were involved were often experimental. For example, it has been shown that concrete ages faster than other materials [17,18], which makes the preservation of historic constructions in concrete a time-constrained activity requiring proactive solutions. Furthermore, given the referred climate change effects that are likely to accelerate concrete degradation, addressing its preservation becomes urgent. Given the importance of this topic, several documents have highlighted the cultural significance of reinforced concrete heritage constructions, namely the Madrid–New Delhi Document [19] and the Cádiz Document [20], discussing the need for their preservation. However, there are no comprehensive methodologies for assessing how the impacts of different types of hazards may affect the cultural significance of such heritage constructions, namely in cases where some of the hazards may be intensified by climate change.

Although research interest about the effects of climate change on cultural heritage has increased significantly over the past 10 years [21,22], many studies have analyzed specific issues that are not related to reinforced concrete heritage constructions. For example, the studies in [23,24] focus on indoor climate conditions and thermal efficiency issues, while the research in [25–27] analyses the impacts of certain natural hazards that are influenced by climate change, but heritage constructions made of reinforced concrete are not addressed. Furthermore, the research focusing on coastal heritage and climate change effects is essentially driven by the emergency of sea level rise and the future of coastal environments [28–30], and there is very little reference to modern architecture or the deterioration of concrete materials. Finally, reference is made to the recent vulnerability assessment methodology proposed in [31], which is applicable to reinforced concrete heritage constructions in different environments. While it seems to be able to consider different types of hazards, including anthropogenic hazards, it does not seem to account for climate change effects or the impacts on cultural significance.

Considering the limited research on the general topic of risk management dedicated to historic reinforced concrete constructions, the objective of the current research is to propose and apply an overarching methodology to illustrate how risk assessment can contribute to the preservation of the cultural significance of this type of heritage in coastal environments. The research was carried out using the Ocean Swimming Pool (Figure 1), in Matosinhos, Portugal, as a pilot site. The Ocean Swimming Pool was designed by the Pritzker Prize winning architect Álvaro Siza and built from 1961 to 1973. In this early work, Siza adopted an expressively modern technology in reinforced concrete over the seaside rocks. The building is currently listed as a National Monument (since 2011) and is included in the "Ensemble of Álvaro Siza's Architectural Works", which is currently on the Tentative List for World Heritage (2017).



Figure 1. Ocean Swimming Pool, Matosinhos, Portugal. Photo: Pixel, 2021.

2. Methodology

The proposed approach can be seen as a simplified first-level assessment framework for identifying relevant hazards, vulnerabilities, and risks in reinforced concrete heritage constructions (Figure 2). The methodology was supported by the analysis of different information sources, with a special focus on the consultation of regional and local-level legal and administrative documents (policies, regulations, reports, maps, etc.). This information was complemented with data collected from interviews conducted with officers of the Municipal Council heading the Culture, Urban Planning, Environment, Civil Protection, and Heritage Commission departments. The identification of hazard impacts took into account the site's values (social, economic, political, historic, aesthetic, scientific, age, and ecological) [32] that contribute to its cultural significance, given their essential nature for the decision-making process about what should be preserved and what can be changed.

The methodology that was followed for risk, vulnerability, and hazard identification considers that risk can be defined as the potential negative impacts on the asset under assessment due to the occurrence of a threatening event, and needs to account for the diversity of values and functions associated with the asset [33]. The threatening events are termed hazards and represent a potentially damaging physical event, natural or anthropogenic, that can have negative impacts on the asset under assessment. These negative impacts represent the risk measure but are often globally termed as losses [34]. Globally, these impacts can be seen as the result of the dynamic interaction between the hazard and existing vulnerabilities (e.g., physical, social, economic, or environmental vulnerabilities) which represent the susceptibility of the asset under assessment to the damaging effects of the hazard, combined with a lack of ability to cope with those impacts, i.e., a lack of resilience [35]. Within this definition, it is noted that the word "potential" refers to the presence of uncertainty when analyzing these issues. The uncertainty can have different sources and occurs across the different elements of the risk assessment, namely when establishing the likelihood of occurrence of the hazard that can cause the negative impacts or when estimating the actual negative impacts.

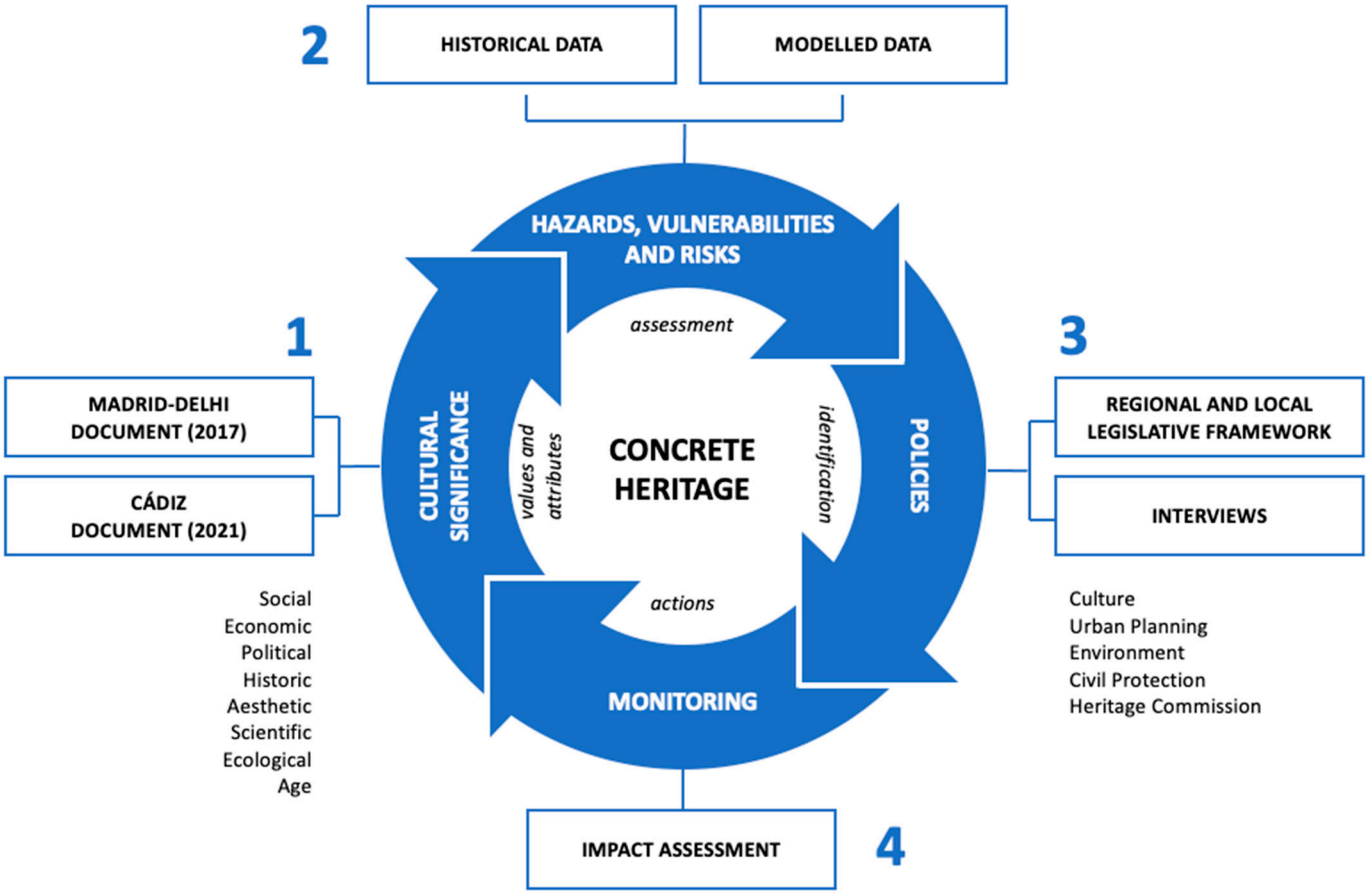


Figure 2. Risk assessment methodology based on cultural significance.

The risk, vulnerability, and hazard identification approach that was considered herein falls into the category of qualitative methods and combines the likelihood and severity of the selected hazard scenarios with the vulnerability levels that were identified to establish risk levels. Regarding the selected hazard scenarios, natural and anthropogenic hazards are considered, including both sudden- and slow-onset hazards, and the likely effects of climate change are also accounted for. Although in a qualitative form, the vulnerability levels that are identified consider physical impacts on the asset (i.e., physical damage) and impacts on the cultural significance and values of the asset. Finally, given the preliminary nature of the proposed analysis, these risk levels must be understood as a tool to establish risk mitigation priorities and identify issues requiring more detailed and resource-demanding analyses.

3. Cultural Significance

The first step of the proposed approach for risk assessment in a cultural heritage context is dedicated to understanding the cultural significance of the asset under analysis to determine what can be threatened or exposed to risk. Cultural significance can be seen as the sum of all the values attributed by the relevant stakeholders connected to the heritage site. Hence, a statement of cultural significance results from identifying the heritage attributes and values of the site, supported by content analysis techniques applied to the evaluation of site documentation, on-site information, and the analysis of the outcomes obtained from various participatory activities [36]. The results of the thematic analysis carried out with all the data collected using various methods tailored to each stakeholder were the basis for identifying the values of the site, following the adapted cultural values taxonomy from Tarrafa Silva and Pereira Roders [32], which considers eight cultural values: social, economic, political, historic, aesthetic, scientific, age, and ecological. This statement of cultural significance provides the essential support that the following

steps of the risk assessment approach will consider when identifying potential threats and preparing mitigation measures or policies.

The social significance of the Ocean Swimming Pool is rooted in the strong relationship that local communities have established with the site since its construction, which occupies an unmistakable place in their collective memory and experience. Moreover, the site has been operating for more than fifty years with its original use, thus retaining economic significance. The Ocean Swimming Pool project was part of a broader political strategy in the 1960s that aimed at transforming Leça da Palmeira into a relevant tourist destination. At the time, Álvaro Siza introduced ideas in this design that had not been attempted before and reflected the architectural debates that were taking place in that historical context. The aesthetic significance of the property relies on its direct association with the nationally and internationally acclaimed architect Álvaro Siza, being one of the first constructions built in Portugal with exposed reinforced concrete and employing a series of innovative solutions that testify to its scientific significance. Also, the age significance is visible throughout the complex in the patinas that several materials exhibit, enhancing the material integrity of the site until today, and that were also preserved in recent conservation works supervised by Álvaro Siza [37]. Finally, its ecological significance rests upon its harmonious integration within the topography and surrounding landscape. To further highlight the statement of the cultural significance of the Ocean Swimming Pool, the following points summarize several key aspects connected to the referred heritage values:

- ✓ Outstanding work within the context of the revision of modernism;
- ✓ Considered a masterpiece by leading international architecture critics;
- ✓ Extensively photographed, filmed, and written about;
- ✓ Expresses a tectonic shift from regionalist-inspired designs towards a more abstract language;
- ✓ Material integrity has been maintained over time;
- ✓ One of the first constructions built with exposed concrete in Portugal, employing innovative construction systems;
- ✓ Reflects a harmonious integration with the surrounding landscape and its topography;
- ✓ Social and cultural landmark for the community;
- ✓ One of the most sought-after attractions in Matosinhos;
- ✓ An exceptional case of an architect preserving his own work while enhancing its significance;
- ✓ Is included in the Tentative List for World Heritage as a component property of "Álvaro Siza's Architecture Works in Portugal" and is listed as a National Monument.

4. Hazards, Vulnerabilities and Risks

4.1. Hazards

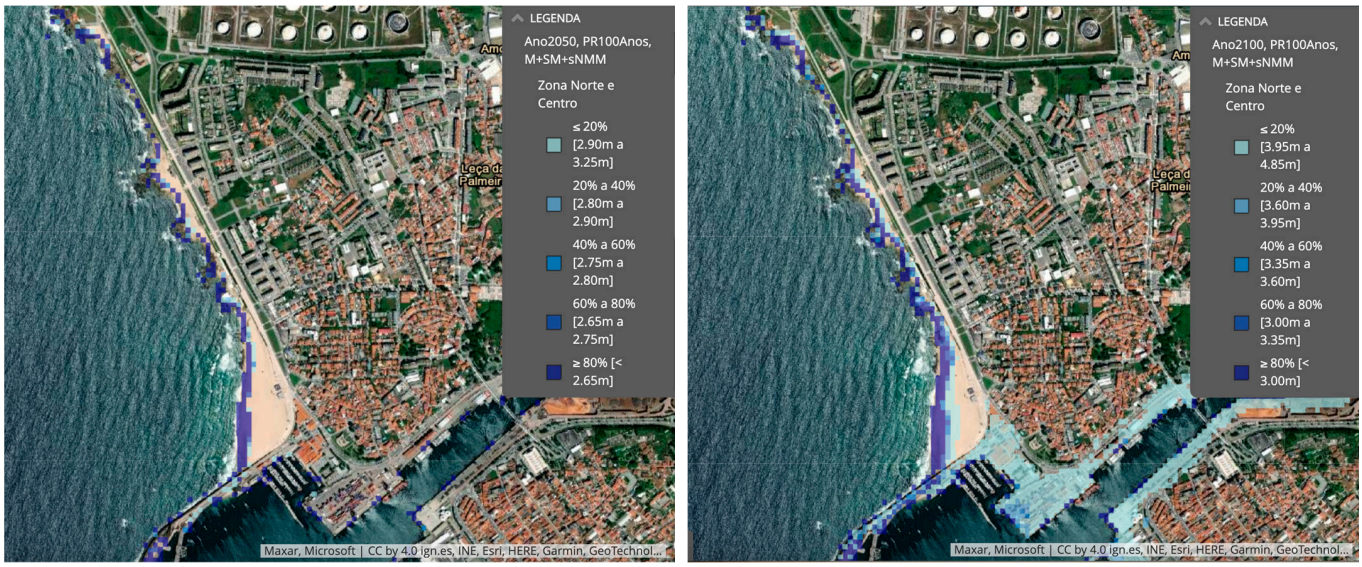
4.1.1. Natural Hazards

Given the location of the Ocean Swimming Pool, the more relevant natural hazards were found to be storm surges and chloride action. In addition, given their relation with climate change, events such as sea level rise and the increase of atmospheric carbon dioxide were also considered in the current assessment.

In terms of chloride action, the most important source of chlorides for the Ocean Swimming Pool is the contact with marine air and splash-water [38]. Chloride concentration will vary according to the nature of the shoreline and the resulting surf, wetting and drying cycles, and wind direction and speed, all of which can vary seasonally and on a daily basis. Additionally, chloride deposition also depends on ambient temperature as well as rainfall regimes that may wash off some of the chlorides. All these variables influence the chloride deposition rate, resulting in a higher or lower deposition of these ions according to the cumulative effect of these conditions [39].

A storm surge is an abnormal rise of seawater over the predicted astronomical tide level that storms generate. These storms originate in low-pressure systems, or depressions, which temporarily increase the sea level by decreasing atmospheric pressure. Due to their

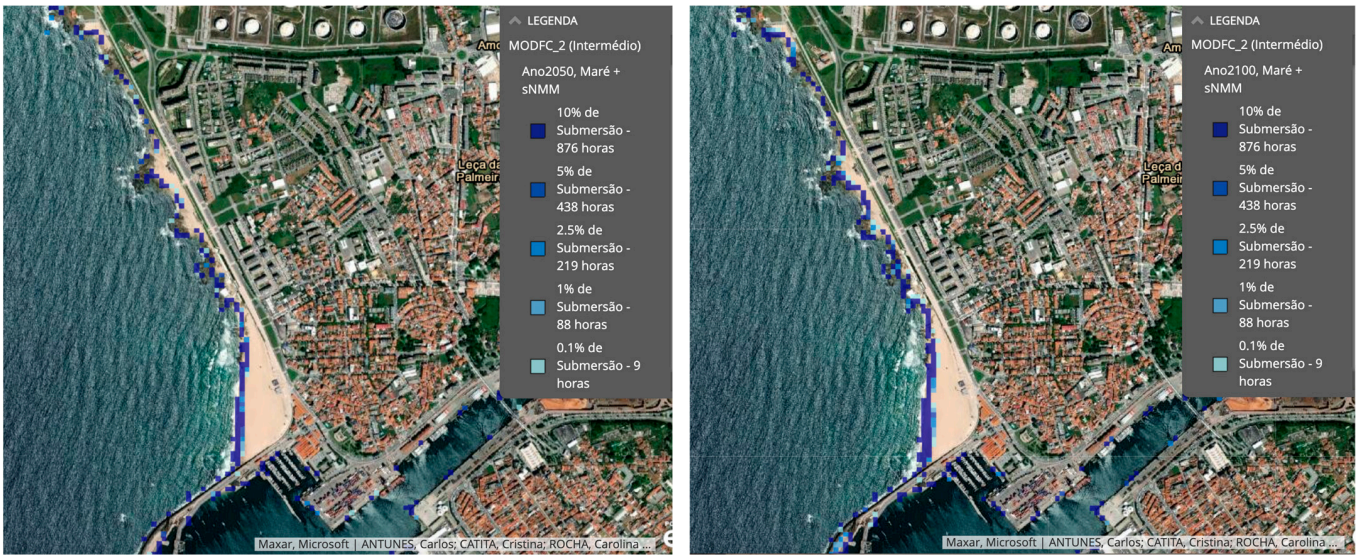
morphology, low and sandy coasts are particularly sensitive to this extreme hydrodynamic phenomenon. In some European regions along the Atlantic coast, storm surges can reach over 2 m above normal tide levels. Nevertheless, the highest recorded values on the Portuguese coast were closer to 1 m [40]. However, one of the effects of climate change might be an increase in storminess along the Portuguese continental coast, which was hit by a significant number of storms between 2010 and 2018: Xynthia (February 2010), Hercules (January 2014), and Emma (March 2018). These eight years concentrate 53% of the total number of coastal flooding occurrences since 1980 [41]. The presented coastal flood scenarios (Figure 3) were based on the Mod.FC_2 projection (0.44 m for 2050 and 1.15 m for 2100 in relation to the vertical datum of Cascais 1938), considering the maximum high tide and additional storm surge with a return period of 100 years, according to the Directive 2007/60/EC [42] (p. 239). These scenarios show a 20% to 40% flood probability (with a water depth between 2.80 m and 2.90 m) in 2050 and of 60% to 80% (with a water depth between 3.00 m to 3.35 m) in 2100 for the site.



(**a**) (**b**)

Figure 3. (**a**) Leça da Palmeira coastline extreme flooding scenario for 2050 after GMSL rise; (**b**) Leça da Palmeira coastline extreme flooding scenario for 2100 after GMSL rise (adapted from [42]). A scale of blue hues, from dark to light, represents the five levels of confidence of the Flood Hazard Index: 1—Very low; 2—Low; 3—Medium; 4—High; 5—Extreme; separated by 20% flood probability intervals.

In the context of climate change and its effects, it is currently known that, from 1880 to 2012, the average global temperature increased by 0.85 °C [43] (p. 40). Given current concentrations and ongoing emissions of greenhouse gases, it is likely that the global mean temperature will continue to rise above the pre-industrial level until the end of this century. The world's oceans will warm and ice melting will continue, leading to an increase in the average height of the ocean surface, designated by Global Mean Sea Level (GMSL). Up to 2050, GSML projections exhibit little scenario dependence and estimate a likely sea level rise of 0.19 m and 0.23 m between the baseline period (1995–2014) and 2050. Beyond 2050, the scenarios increasingly diverge. Between the baseline period (1995–2014) and 2100, processes in whose projection there is medium confidence estimate a likely GSML rise between 0.44 m and 0.77 m [44] (p. 1302). The specific sea level rise projections for the west coast of Portugal, based on the intermediate hazard scenario Mod.FC 2b, point to permanent tide submersion levels of 0.44 m in 2050 and of 1.15 m in 2100, relative to the Cascais Vertical Datum 1938 [45]. The specific tide submersion scenarios for 2050 and 2100 in the area of the swimming pools (Figure 4) indicate that, for the latter, both swimming pools are likely to be submerged for 9 h a year.



(**a**) (**b**)

Figure 4. (**a**) Leça da Palmeira coastline tide submersion scenario for 2050 after GMSL rise; (**b**) Leça da Palmeira coastline tide submersion scenario for 2100 after GMSL rise (adapted from [42]). A scale of blue hues, from dark to light, represents the percentage of submersion hours and its absolute values during the year: 10% or 876 h; 5% or 438 h; 2.5% or 219 h; 1% or 88 h; 0.1% or 9 h.

Given its relation with climate change, the impact of the rise in atmospheric CO_2 is also considered herein. As referred before, the rise of atmospheric CO_2 concentration can lead to an increase in concrete carbonation, which in turn leads to a non-negligible increase in carbonation-induced corrosion of steel reinforcement. Carbon dioxide levels are higher today than at any point in human history, mostly as a result of anthropogenic emissions (e.g., burning of fossil fuels for energy). In 2022, according to the Global Monitoring Lab of the National Oceanic and Atmospheric Administration (NOAA), global average atmospheric carbon dioxide was 417.06 ppm [46].

It is expected that, with higher atmospheric CO_2 concentration, the proportion of emissions taken up by both ocean and land will decline. Thus, even if there is considerable uncertainty in projections of future CO_2 concentration, the IPCC projections lead to a CO_2 concentration for 2010 that ranges from 651 to 682 ppm [47] (p. 222).

4.1.2. Anthropogenic Hazards

Given the location and past history of the Ocean Swimming Pool, vandalism, incorrect or improper use, and neglect or lack of maintenance were the three types of anthropogenic hazards considered in the current analysis.

Vandalism, characterized by acts that cause deliberate damage or even destruction, has been a persistent issue throughout history. Regardless of the underlying motivations, the consequences of vandalism inflict willful damage upon the material landscape of cultural heritage constructions. These malicious acts can take various forms, such as graffiti, defacement, theft of valuable artifacts, or intentional physical damage to structures. Vandalism not only causes irreversible harm to a heritage site but also disrupts its historical context and erodes the collective memory embedded within these sites.

Heritage constructions that retain their original purpose and remain accessible to the general public often face issues related to incorrect or improper use. The continuous flow of visitors and the lack of proper monitoring can lead to increased wear and tear, potentially compromising the structural stability and authenticity of the site. Inadequate visitor management can further exacerbate the damage caused by incorrect use.

Long-term neglect or insufficient maintenance poses a pervasive threat to heritage constructions worldwide. The passage of time, exposure to natural elements, and lack of

regular upkeep can lead to significant deterioration of historic structures. Although maintenance is essential for ensuring the long-term preservation of cultural heritage constructions, stakeholders often neglect systematic and routine maintenance works. This neglect can arise due to a lack of understanding about the unique needs of these structures, as well as the unavailability or inconsistent allocation of resources.

4.1.3. Classification of the Hazard Scenarios

Table 1 presents a summary of the previously described hazard scenarios along with a likelihood classification using three levels: LOW, MEDIUM, and HIGH. For the slow-onset natural hazards related to climate change, this classification reflects the confidence in the climate model that predicts the event. In contrast, for the case related to chloride action, whose classification is HIGH, it reflects the fact that the asset is continuously exposed to that hazard. For anthropogenic hazards, the classification reflects the likelihood of the hazard occurring at least once a year.

Table 1. Summary of the selected hazard scenarios.

Category	Hazard	Scenario	Description
Slow-onset natural hazard	Sea level rise	Sea level rise of 0.44 m until 2050 Likelihood: HIGH	Likely sea level rise at west coast of Portugal according to scientists
Slow-onset natural hazard	Increase in atmospheric carbon dioxide	Atmospheric CO_2 increase between 236–267 ppm until 2100 Likelihood: HIGH	Likely atmospheric CO_2 increase according to the Intergovernmental Panel on Climate Change (IPCC)
Slow-onset natural hazard	Chloride action	Permanent marine environment exposure Likelihood: HIGH	The asset is permanently exposed to the effect of airborne chlorides carried by the sea winds
Sudden-onset natural hazard	Storm surge	Occurrence of a storm surge Likelihood: HIGH	The asset's location makes it particularly vulnerable to storm surges and coastal flooding
Sudden-onset anthropogenic hazard	Vandalism	Theft of copper elements and graffiti Likelihood: LOW	The absence of clear fences and the low height of the building's roof make the site particularly vulnerable to trespassing and vandalism
Slow-onset anthropic hazard	Misuse	Throwing waste into toilet vases Likelihood: MEDIUM	Throwing waste into toilet vases might lead to clogging and repair costs
Slow-onset anthropogenic hazard	Lack of maintenance	Absence of regular surveys Likelihood: MEDIUM	The absence of regular surveys prevents the early identification of pathologies and leads to costly and more difficult repairs in the future

4.2. Vulnerabilities

4.2.1. Vulnerability to Natural Hazards

Sea level rise is particularly threatening to coastal structures such as the Ocean Swimming Pool. The entrance level of the property from the street is at +7.50 m above the sea level, while the changing rooms and the swimming tanks were built at +5.00 m and +2.90 m above the current sea level, respectively. As such, there is an increased likelihood for the swimming tanks to be impacted by wave overtopping in future storms, but also in normal conditions if seal level rise reaches significant values (wave height above 2 m are rather common under normal weather conditions). This particular vulnerability of the Ocean Swimming Pool is made visible through the simulation presented in Figure 5, which shows the impact of a 1.00 m sea level rise in terms of the area reached by water in these conditions and its closeness to the larger swimming tank.

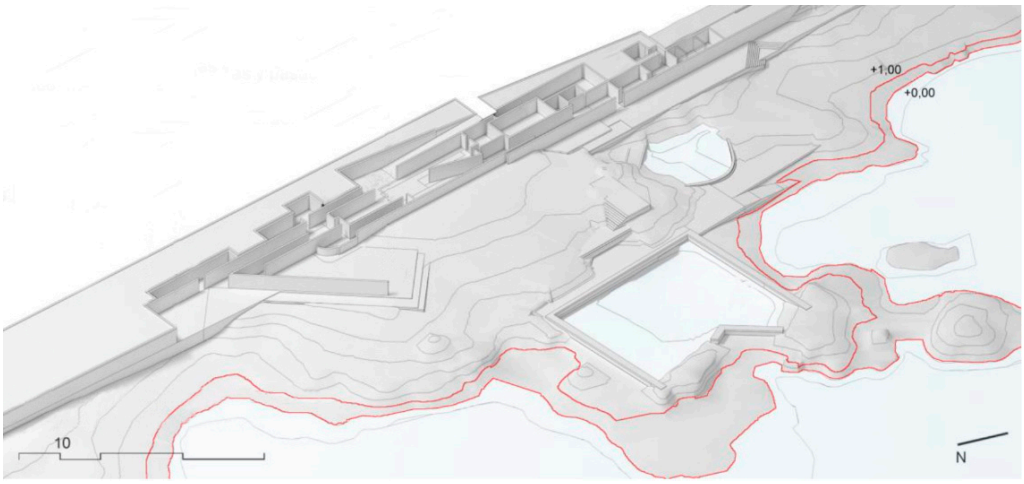


Figure 5. Graphic representation (in red) of a +1.00 m sea level rise (adapted from [48]).

The durability of concrete in coastal areas is mainly determined by its deterioration over time, which is affected by the exposure conditions of the surrounding environment. In such an environment, the penetration of chlorides in concrete structures increases the likelihood of rebar corrosion, resulting in cracking and delamination of the concrete cover and a subsequent reduction of the reinforcement cross section, which seriously affects the load-bearing capacity of structural elements [49] (p. 242). In addition to this issue, climate change is likely to cause an acceleration of deterioration processes that will also affect the safety and serviceability of concrete infrastructures. In this context, the main driver for increased concrete deterioration is the atmospheric CO_2 concentration. The increase in CO_2 levels is expected to increase the likelihood of concrete carbonation [10–13], which in turn leads to a non-negligible increase in carbonation-induced rebar corrosion [14–16], as referred before. This impact of climate change on existing infrastructures is expected to be considerable, as corrosion damage is disruptive and costly to repair [11] (p. 1326).

The vulnerability of coastal constructions also needs to be considered regarding the occurrence of storm surges, given their immediate and prolonged impacts, as mentioned in Section 4.1.1, namely damage to the swimming pool tanks and the retaining walls. During a surge, the combined moving force of waves and wind may lead to damage to the constructions, as well as to the infrastructures, including access roads and electrical or hydraulic networks. Wave overtopping, overwashing, and flooding of coastal areas are likely to occur during these surges, exposing the concrete surfaces to direct contact with seawater and increasing the level of chloride deposition, which will significantly decrease the lifespan of the building. After the surge, ground subsidence and increasing coastal erosion can occur, which, in turn, may create more damage to constructions and hydraulic networks. Furthermore, suspended sediments and materials in the seawater may mechanically degrade the concrete surfaces and clog the water supply and filtering systems, compromising their normal working conditions.

These extreme events are more clearly illustrated by Figures 6 and 7, which pinpoint the exact extension each surge had and its immediate impacts on the Ocean Swimming Pool between 2017 and 2019. It is noted that the 2011 Matosinhos Municipal Plan for Civil Protection Emergency [50] rates storm surges with overwashing of the coastline with a medium-low level risk, meaning a low frequency (e.g., one time every 5 years). However, given the apparent increase in the rate of occurrence of these events, there is a need to review this rating based on empirical data combined with the outcomes of numerical simulations.

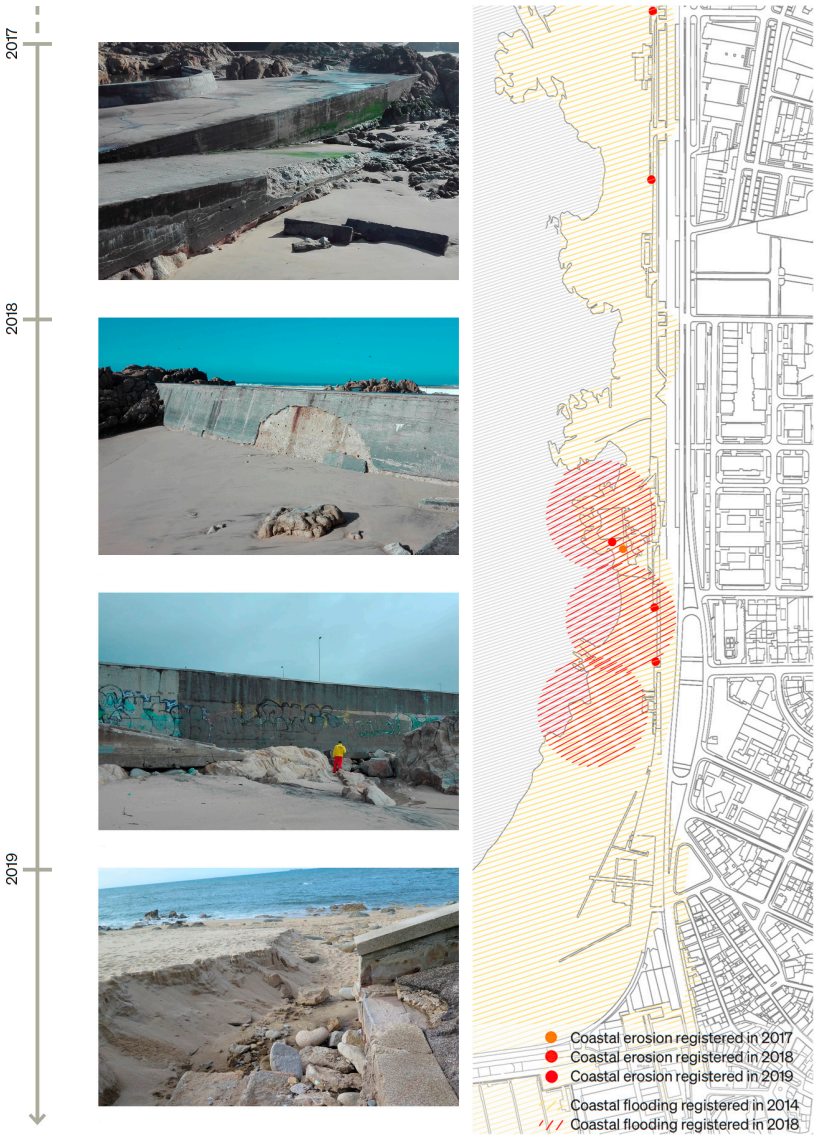


Figure 6. Graphic representation of flooding and coastal erosion occurrences between 2014 and 2019. Photo: Civil Protection Department of the Municipal Council of Matosinhos, 2017–2019.



Figure 7. Wave overtopping during a storm surge. Photo: Civil Protection Department of the Municipal Council of Matosinhos, 2018.

4.2.2. Vulnerability to Anthropogenic Hazards

Due to the site's natural setting along a continuous stretch of beaches, it has no clear limits or fencing, making it vulnerable to trespassing, vandalism, and theft. Therefore, the building is particularly exposed to damaging anthropogenic activities such as wall inscriptions like graffiti, material destruction, or theft of valuable materials like copper. As most of the walls of the asset are made of exposed concrete, they cannot be painted over, which increases the difficulty of removing graffiti. Also, its low-lying copper roof is tempting given the rise in the price of this material. Copper theft of the roof's sheeting or of water fixtures affects the normal operating conditions of the asset, resulting in the occurrence of anomalies that might have serious consequences if not promptly addressed. The permanent presence of a security guard can mitigate these vulnerabilities.

The Ocean Swimming Pool has been permanently operational since it opened in 1965. Since then, it has been visited by an average of sixty thousand people each year (based on available data from 2018 shared by the Matosinhos Municipal Council). As a result, the asset is vulnerable to unintentional damage from intensive use or willful damage from improper use. As it is a fully functional public facility, some of the issues that can occur are difficult to prevent, such as clogged toilet vases due to improper waste disposal, or damaged showers and water faucets.

The lack of a structured and clearly defined maintenance policy facilitates the occurrence of uncontrolled degradation of the asset, compromising its preservation for future generations. The development and implementation of maintenance plans not only ensure the execution of regular visual inspections and scheduled material replacement but also define intervention guidelines that should prevent unauthorized or incorrect interventions that may hinder the significance of the site. Adequate maintenance plans therefore allow the prompt identification of anomalies and provide guidance for the most adequate response to these anomalies.

4.2.3. Classification of the Vulnerability Scenarios

Table 2 presents a summary of the previously described vulnerability scenarios along with a severity classification using three levels: LOW, MEDIUM, and HIGH. This classification considers both the severity of the physical damage that can occur as well as the severity of the impact on the cultural values that can be affected. A severity level classified as LOW means that the physical damage is either negligible or small enough to be easily reparable, while the impacts to cultural values are also expected to be negligible. A severity level classified as MEDIUM means that the physical damage is not negligible and repairing it will also involve non-negligible costs. This damage will also have relevant impacts to cultural values, but these are also expected to be recoverable after the damage repair. A severity level classified as HIGH means that the physical damage is expected to be significant and may not be fully repairable. As such, the impacts to cultural values in this case may not be recoverable.

Table 2. Summary of the selected vulnerability scenarios.

Affected Cultural Values	Hazard	Vulnerability	Description
All	Sea level rise	Permanent submersion Severity: HIGH	Sea level rise, as a result of climate change, implies the permanent submersion of the asset, preventing its fruition in the future.
Aesthetic	Increase of atmospheric carbon dioxide	Acceleration of concrete carbonation and rebar corrosion Severity: MEDIUM	As a result of climate change, the increase of atmospheric carbon dioxide will accelerate concrete carbonation, leading to the corrosion of steel rebars, which can cause cracking, spalling and the weakening of reinforced concrete elements.

Table 2. *Cont.*

Affected Cultural Values	Hazard	Vulnerability	Description
Aesthetic	Chloride action	Acceleration of rebar corrosion Severity: MEDIUM-HIGH	The permanent exposure to the maritime environment, which is richer in chlorides, accelerates the corrosion of steel rebars, which can cause cracking, spalling and the weakening of reinforced concrete elements.
Economic Aesthetic	Storm surge	Building damage Infrastructural damage Severity: HIGH	The moving force of a storm surge may result in physical damage. Direct exposure to seawater will seriously compromise the normal operating conditions of infrastructural networks due to direct contact with water, chlorides, or the water-suspended sediments that can clog the hydraulic and filtering systems.
Economic Aesthetic	Vandalism	Graffiti Copper theft Severity: MEDIUM-LOW	Graffiti have a negative impact on the asset's image and may be particularly difficult to remove since the asset was built mainly with unprotected materials (exposed concrete). Copper theft from the roof sheets or the water pipes and outlets affects the normal operating conditions of the asset and might lead to serious consequences if not promptly addressed.
Economic	Misuse	Equipment damage Severity: MEDIUM-LOW	The misuse of the swimming pool facilities might lead to equipment damage and determine the need for unexpected repairs and additional costs.
Economic Aesthetic	Lack of maintenance	Acceleration of the asset's degradation Severity: MEDIUM-HIGH	The lack of regular and appropriate maintenance interventions will accelerate the degradation of the asset.

4.3. Risk Level

Table 3 presents the risk levels that were identified for the selected hazard and vulnerability scenarios. The risk levels were classified into four levels:

- Acceptable risk without the need to implement any action—this is a negligible risk level;
- Acceptable risk with the implementation of monitoring actions—this is a negligible risk level but actions for monitoring the evolution of the conditions of the asset are recommended to understand if the risk level is increasing, due to a change in the hazard or in the vulnerability;
- Tolerable risk—this represents a non-negligible risk level for which mitigation actions are only expected to be implemented if the results of a cost–benefit analysis are favorable;
- Unacceptable risk—this represents a non-negligible risk level for which mitigation actions must be implemented urgently.

Table 3. Risk level for the identified hazards and vulnerability scenarios.

Hazard	Scenario (Likelihood)	Vulnerability (Severity)	Risk Level
Sea level rise	HIGH	HIGH	Unacceptable risk
Increase of atmospheric carbon dioxide	HIGH	MEDIUM	Tolerable risk
Chloride action	HIGH	MEDIUM-HIGH	Unacceptable risk
Storm surge	HIGH	HIGH	Unacceptable risk
Vandalism	LOW	MEDIUM-LOW	Acceptable risk without the need to implement any action
Misuse	MEDIUM	MEDIUM-LOW	Acceptable risk with the implementation of monitoring actions
Lack of maintenance	LOW	MEDIUM-HIGH	Acceptable risk with the implementation of monitoring actions

5. Policies

As discussed in Section 4, it is crucial to acknowledge and understand the impacts that natural and anthropogenic hazards have on the Ocean Swimming Pool, in particular those whose effects are intensified by climate change to ensure they are prevented, mitigated, or, when that is not possible, that adaptation measures are implemented. These hazards were already identified, and scenarios and their likelihood were established, as well as the corresponding vulnerability in terms of the expected severity, in order to assess risk levels for these scenarios. However, it is important to mention that mitigation measures may, in some cases, also irreversibly affect cultural significance. Therefore, in such cases, it is essential to, instead, think of adapting to the present and future impacts the hazards will have on the infrastructure, focusing on the preservation of heritage values, and ensuring that adequate preparedness is in place when such events occur [51].

A flexible emergency plan that considers multiple post-disaster scenarios would restore the situation back to normal as rapidly and efficiently as possible. As recommended by several disaster recovery guidelines, proactive measures should consider a disaster risk management cycle [52], which includes practical guidance, signage, and staff training before an emergency, an adequate and efficient emergency response during the event, and damage assessment, treatment, and recovery after the trauma to avoid post-damage vulnerabilities and recurring problems.

The challenges, though, may rest in coordinating existing plans and legislative frameworks to include this disaster management cycle and produce effective mitigation/adaptation measures. Interviews with different stakeholders are an excellent tool to assess most of these gaps. Therefore, in order to cross-reference different management plans and promote collaboration, the following policies were developed (Table 4) to provide an integrated response focusing on the preservation of the cultural significance described in Section 3, for scenarios that could affect the integrity of the property.

Table 4. Policy response to adverse scenarios and to preserve cultural significance.

Policy Group	Policy	Description
Risk Management Plan	Risk Management	Develop and implement a Risk Management Plan that includes regular risk assessments, the development of mitigation/adaptation measures, and emergency preparedness measures.
	Disaster Recovery	Develop and anticipate lines of action for emergency response and disaster recovery.

Table 4. *Cont.*

Policy Group	Policy	Description
Climate Change Adaptation	Adaptation Measures	Compile a set of measures, or actions (as a study case), for implementation in other cases with similar constraints, to help other listed sites to adapt to climate change. Similarly, the knowledge obtained from this case study should also suggest additional measures or guidelines for local and regional policies.
	Permanent Flooding	Study of future lines of action for building conservation in case of permanent damage or flooding that compromises the normal use of the built structures and infrastructures (e.g., the construction of more permanent protection measures like walls or spurs).
	Staff Training	Train staff/stakeholders and inform users on more efficient management strategies, and promote the use of sustainable practices while working, using, or managing the Pool. The development of participatory activities, presentations, or workshops to raise public awareness on appropriate mitigation/adaptation measures would be beneficial to the implementation of these strategies.
	Archival Information	Organize an archive containing exhaustive information on the Ocean Swimming Pool (3D and 2D mapping, visual information, etc.) to ensure its proper reconstruction and future preservation in case there is damage or material loss.

6. Implementation, Monitoring, and Impact Assessment

Monitoring and evaluating the management framework is the last step of the proposed approach. For the case of a listed property, this is a necessary component of the management plan to ensure that the management process is performing as intended, according to established rules, and meeting the external reporting requirements [53]. Monitoring, then, can be defined as a cyclical planning process whose activities are supported by conservation evaluations and impact assessments regularly carried out [54]. As a form of preventive management, monitoring also requires awareness of threats and impacts that take into consideration the vulnerability of the site. Therefore, attention to hazards can help the monitoring process and guarantee heritage protection and conservation.

The monitoring process of the Ocean Swimming Pool was developed based on qualifying when and how corrective measures should be regularly implemented, but also on accepting inputs such as spontaneous reporting and on suggesting new forms of articulation and organization (i.e., a memorandum of understanding). This system facilitates multidisciplinary decision-making to achieve strategic objectives.

Since this goal is also subjected to indicators linked to the site's content and its integrity and authenticity, one level of monitoring must convey general information related to the responsible operation of the site, which, namely, ensures that cultural significance is being preserved. Another level of monitoring, which must be combined with the previous one, is based on considering the pressing hazards, vulnerabilities, and levels of risk assessed for the site (Table 5). These risk levels are then associated with priority levels through a scale in which the unacceptable ones must be prioritized in the monitoring process in case immediate mitigation measures cannot be implemented (Table 6).

Table 5. First level for monitoring based on specific subjects.

Subject	Action	Periodicity	Responsibility
Authenticity and Integrity	Verify the condition of the elements under ranges of authenticity and integrity.	Annually	Advisory Board
Finance	Review and evaluate the budget available for maintenance, repairs, and conservation of the property.	Annually	Matosinhos Sport

Table 5. *Cont.*

Subject	Action	Periodicity	Responsibility
Buffer Zone	Identify irregular interventions in protected area; Identify if there are changes in land use within the protected area.	Annually	Municipal Council of Matosinhos
Real Estate Development	Identify real estate developments in the surrounding area and analyze impacts on the property.	Annually	Municipal Council of Matosinhos
Management	Evaluate the application of maintenance plans and provide reports.	Annually	Matosinhos Sport
Responsible Visitation	Count the number of daily visits as guided visits (tours) to identify the number of people in the building; Define building capacity according to the effect it has on the property.	Daily	Matosinhos Sport
Responsible Use	Identify changes in the behavior of visitors after implementing the "good practices" manual; Report the number of incidents created by visitors not following the rules.	As reported	Matosinhos Sport

Table 6. Second level for monitoring according to levels of priority, performed annually.

Hazard	Risk Level	Priority	Monitoring Method
Sea level rise	Unacceptable	1	Regular monitoring of sea level rise to understand the likelihood of damage to the property and identify measures that can minimize the expected impacts.
Increase of atmospheric carbon dioxide	Tolerable	3	Regular monitoring of concrete elements to maximize the likelihood of early damage detection, and minimize the level of repair that might be needed.
Chloride action	Unacceptable	1	Regular monitoring of concrete elements to maximize the likelihood of early damage detection, and minimize the level of repair that might be needed.
Storm surge	Unacceptable	1	Regular monitoring of concrete elements and other components that may be damaged by storm surges, to maximize the likelihood of early damage detection, and minimize the level of repair that might be needed.
Vandalism	Acceptable	4	Regular monitoring of components prone to vandalism to maximize the likelihood of early damage detection, and minimize the level of repair that might be needed.
Misuse	Acceptable with monitoring actions	2	Regular monitoring of components prone to misuse, to maximize the likelihood of early damage detection, and minimize the level of repair that might be needed.
Lack of maintenance	Acceptable with monitoring actions	2	Regular monitoring of components prone to weathering over time, to maximize the likelihood of early damage detection and minimize the level of repair that might be needed.

These data will be obtained through reports of operational routines in the property. In addition, information surveyed by different experts is necessary, as well as field observation by researchers or specialists, and legislation analyses that incorporate its possible evolution. When impact assessments are not required by national and supra-national frameworks for all interventions affecting the site, employing a Heritage Impact Assessment or "stand alone" impact assessment may widen the reach of the management system.

7. Conclusions

The presented research addresses the risk management of reinforced concrete heritage constructions, focusing on the preservation of their cultural significance in coastal environments. This type of heritage has been largely unaddressed by risk-related research, and the proposed methodology shows how risk assessment can contribute to safeguarding these heritage sites, particularly when faced with threatening events such as coastal erosion and sea level rise induced by climate change. By using the Ocean Swimming Pool by Álvaro Siza in Matosinhos, Portugal as a pilot study, the article showcases the practicality and adaptability of the proposed approach.

The pilot study has highlighted the importance of understanding the cultural significance of the Ocean Swimming Pool to better determine what elements are at risk. Furthermore, it also emphasized the importance of using different sources of information, ranging from documentation and on-site data to activities with local communities, in order to understand the full scale of tangible and intangible attributes and values of the site.

The results obtained for the Ocean Swimming Pool establish a clear ranking of the hazards that create relevant levels of risk. Among those, risk levels associated with chloride action and storm surges, as well as those connected to the ongoing sea level rise, were identified as those needing the most urgent actions. However, risk levels connected with the ongoing increase of atmospheric carbon dioxide and its ability to intensify the likelihood of corrosion, as well as anthropogenic hazards such as misuse and lack of maintenance, were also flagged as non-negligible.

Backed up by the identification of existing policies and planning instruments, as well as data collected from interviews with different stakeholders, a monitoring process was then proposed. This process includes a series of actions that should be implemented regularly on an annual basis to maximize the likelihood of early damage detection and minimize the level of repair that might be needed. No specific repair actions were established, though, since these will need to be defined based on the conditions that are found during the monitoring process.

The Ocean Swimming Pool case study highlights the relevance of a risk-based management approach. By using a systematic risk-based framework aiming at preserving cultural significance, a roadmap for preservation and adaptation has been illustrated, providing an example for heritage constructions in similar coastal environments. The proposed methodology also illustrates how cultural values can be integrated into risk management and conservation policies. Although existing studies on risk management at heritage sites have been valuable, they often overlook the specific impact that hazards can have on cultural significance. The proposed methodology is a flexible framework that associates the expected impacts of natural and anthropogenic hazards with key heritage values, facilitating the development of appropriate mitigation/adaptation actions and policies to preserve those values. Furthermore, by including climate-change-induced threats in the analysis, the methodology paves the way for developing more effective adaptation strategies to preserve concrete coastal heritage for future generations.

Author Contributions: Conceptualization, T.C.F., X.R. and P.M.F.; methodology, T.C.F. and X.R.; formal analysis, X.R. and H.M.; investigation, T.C.F., X.R. and H.M.; data curation, X.R. and H.M.; writing—original draft preparation, T.C.F., X.R., P.M.F. and H.M.; writing—review and editing, X.R., H.M. and P.M.F.; supervision, T.C.F.; project administration, T.C.F.; funding acquisition, T.C.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Getty Foundation, under the "Keeping It Modern" Program (Grant ORG-202047064), as well as by the European Regional Development Fund (ERDF) through 820 COMPETE 2020—Operational Programme for Competitiveness and Internationalisation 821 (OPCI), and by national funds through FCT/MCTES (PIDDAC), under the scope of the projects POCI-01-0145-FEDER-822 007744, 2020.01980.CEECIND, SIZA/ETM/0023/2019, and Base Funding—UIDB/04708/2020 of CONSTRUCT—Instituto de I&D em Estruturas e Construções.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Mehta, P.K. *Performance of Concrete in Marine Environment*; American Concrete Institute: Farmington Hills, MI, USA, 1980.
2. Santhanam, M.; Otieno, M. Deterioration of concrete in the marine environment. In *Marine Concrete Structures: Design, Durability and Performance*; Alexander, M., Ed.; Woodhead Publishing: Cambridge, UK, 2016; pp. 137–149.
3. Qu, F.; Li, W.; Dong, W.; Tam, V.W.; Yu, T. Durability deterioration of concrete under marine environment from material to structure: A critical review. *J. Build. Eng.* **2021**, *35*, 102074. [CrossRef]
4. James, A.; Bazarchi, E.; Chiniforush, A.A.; Aghdam, P.P.; Hosseini, M.R.; Akbarnezhad, A.; Martek, I.; Ghodoosi, F. Rebar corrosion detection, protection, and rehabilitation of reinforced concrete structures in coastal environments: A review. *Constr. Build. Mater.* **2019**, *224*, 1026–1039. [CrossRef]
5. Pranzini, E.; Wetzel, L.; Williams, A.T. Aspects of coastal erosion and protection in Europe. *J. Coast. Conserv.* **2015**, *19*, 445–459. [CrossRef]
6. Gomes, M.P.; Santos, L.; Pinho, J.L.; Antunes do Carmo, J.S. Hazard assessment of storm events for the Portuguese northern coast. *Geosciences* **2018**, *8*, 178. [CrossRef]
7. Masselink, G.; Russell, P. Impacts of climate change on coastal erosion. *MCCIP Sci. Rev.* **2013**, 71–86. [CrossRef]
8. Stott, P. How climate change affects extreme weather events. *Science* **2016**, *352*, 1517–1518. [CrossRef]
9. Konisky, D.M.; Hughes, L.; Kaylor, C.H. Extreme weather events and climate change concern. *Clim. Chang.* **2016**, *134*, 533–547. [CrossRef]
10. Yoon, I.S.; Çopuroğlu, O.; Park, K.B. Effect of global climatic change on carbonation progress of concrete. *Atmos. Environ.* **2007**, *41*, 7274–7285. [CrossRef]
11. Stewart, M.G.; Wang, X.; Nguyen, M.N. Climate change impact and risks of concrete infrastructure deterioration. *Eng. Struct.* **2011**, *33*, 1326–1337. [CrossRef]
12. Talukdar, S.; Banthia, N.; Grace, J.R. Carbonation in concrete infrastructure in the context of global climate change–Part 1: Experimental results and model development. *Cem. Concr. Compos.* **2012**, *34*, 924–930. [CrossRef]
13. Xu, Z.; Zhang, Z.; Huang, J.; Yu, K.; Zhong, G.; Chen, F.; Chen, X.; Yang, W.; Wang, Y. Effects of temperature, humidity and CO2 concentration on carbonation of cement-based materials: A review. *Constr. Build. Mater.* **2022**, *346*, 128399. [CrossRef]
14. Stewart, M.G.; Wang, X.; Nguyen, M.N. Climate change adaptation for corrosion control of concrete infrastructure. *Struct. Saf.* **2012**, *35*, 29–39. [CrossRef]
15. Zhou, Y.; Gencturk, B.; Willam, K.; Attar, A. Carbonation-induced and chloride-induced corrosion in reinforced concrete structures. *J. Mater. Civ. Eng.* **2015**, *27*, 04014245. [CrossRef]
16. Köliö, A.; Honkanen, M.; Lahdensivu, J.; Vippola, M.; Pentti, M. Corrosion products of carbonation induced corrosion in existing reinforced concrete facades. *Cem. Concr. Res.* **2015**, *78*, 200–207. [CrossRef]
17. Di Biase, C. (Ed.) *Il Degrado del Calcestruzzo Nell'architettura del Novecento*; Maggioli: Santarcangelo di Romagna, Italy, 2009.
18. Croft, C.; Macdonald, S. (Eds.) *Concrete: Case Studies in Conservation Practice*; Getty Publications: Los Angeles, CA, USA, 2018.
19. ICOMOS ISC20C. *Approaches to the Conservation of Twentieth-Century Cultural Heritage Madrid–New Delhi Document*. ICOMOS ISC20C. 2017. Available online: https://openarchive.icomos.org/id/eprint/2692 (accessed on 20 August 2023).
20. ICOMOS ISC20C. *The Cádiz Document. InnovaConcrete Guidelines for Conservation of Concrete Heritage*. ICOMOS ISC20C. 2021. Available online: https://openarchive.icomos.org/id/eprint/2578 (accessed on 20 August 2023).
21. Sesana, E.; Gagnon, A.S.; Ciantelli, C.; Cassar, J.; Hughes, J.J. Climate change impacts on cultural heritage: A literature review. *Wiley Interdiscip. Rev. Clim. Chang.* **2021**, *12*, e710. [CrossRef]
22. Fatorić, S.; Seekamp, E. Are cultural heritage and resources threatened by climate change? A systematic literature review. *Clim. Chang.* **2017**, *142*, 227–254. [CrossRef]
23. Leissner, J.; Kilian, R.; Kotova, L.; Jacob, D.; Mikolajewicz, U.; Broström, T.; Ashley-Smith, J.; Schellen, H.L.; Martens, M.; van Schijndel, J.; et al. Climate for culture: Assessing the impact of climate change on the future indoor climate in historic buildings using simulations. *Herit. Sci.* **2015**, *3*, 38. [CrossRef]
24. Biseniece, E.; Žogla, G.; Kamenders, A.; Purviņš, R.; Kašs, K.; Vanaga, R.; Blumberga, A. Thermal performance of internally insulated historic brick building in cold climate: A long term case study. *Energy Build.* **2017**, *152*, 577–586. [CrossRef]
25. Ravankhah, M.; de Wit, R.; Argyriou, A.V.; Chliaoutakis, A.; Revez, M.J.; Birkmann, J.; Žuvela-Aloise, M.; Sarris, A.; Tzigounaki, A.; Giapitsoglou, K. Integrated Assessment of Natural Hazards, Including Climate Change's Influences, for Cultural Heritage Sites: The Case of the Historic Centre of Rethymno in Greece. *Int. J. Disaster Risk Sci.* **2019**, *10*, 343–361. [CrossRef]
26. Bosher, L.; Kim, D.; Okubo, T.; Chmutina, K.; Jigyasu, R. Dealing with multiple hazards and threats on cultural heritage sites: An assessment of 80 case studies. *Disaster Prev. Manag. Int. J.* **2020**, *29*, 109–128. [CrossRef]

27. Sesana, E.; Gagnon, A.S.; Bonazza, A.; Hughes, J.J. An integrated approach for assessing the vulnerability of World Heritage Sites to climate change impacts. *J. Cult. Herit.* **2020**, *41*, 211–224. [CrossRef]
28. Reeder-Myers, L.A. Cultural Heritage at Risk in the Twenty-First Century: A Vulnerability Assessment of Coastal Archaeological Sites in the United States. *J. Isl. Coast. Archaeol.* **2015**, *10*, 436–445. [CrossRef]
29. Kunte, P.D.; Jauhari, N.; Mehrotra, U.; Kotha, M.; Hursthouse, A.S.; Gagnon, A.S. Multi-hazards coastal vulnerability assessment of Goa, India, using geospatial techniques. *Ocean. Coast. Manag.* **2014**, *95*, 264–281. [CrossRef]
30. Rizzi, J.; Torresan, S.; Zabeo, A.; Critto, A.; Tosoni, A.; Tomasin, A.; Marcomini, A. Assessing storm surge risk under future sea-level rise scenarios: A case study in the North Adriatic coast. *J. Coast. Conserv.* **2017**, *21*, 453–471. [CrossRef]
31. Mollá, L.D.; Sagarna, M.; Zabaleta, A.; Aranburu, A.; Antiguedad, I.; Uriarte, J.A. Methodology for assessing the vulnerability of built cultural heritage. *Sci. Total Environ.* **2022**, *845*, 157314. [CrossRef]
32. Tarrafa Silva, A.; Pereira Roders, A. Cultural Heritage Management and Heritage (Impact) Assessments. In *Proceedings of the Joint CIB W070, W092 & TG72 International Conference on Facilities Management, Procurement Systems and Public Private Partnership*; Michell, K., Bowen, P., Cattell, K., Eds.; Department of Construction Economics and Management. University of Cape Town: Cape Town, South Africa, 2012; pp. 375–382. ISBN 978-0-620-50759-2. Available online: https://www.irbnet.de/daten/iconda/CIB_DC24053.pdf (accessed on 20 August 2023).
33. Reisinger, A.; Howden, M.; Vera, C.; Garschagen, M.; Hurlbert, M.; Kreibiehl, S.; Mach, K.J.; Mintenbeck, K.; O'Neill, B.; Pathak, M.; et al. *The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2020.
34. GFDRR. Understanding Risk in an Evolving World: Emerging Best Practices in Natural Disaster Risk Assessment. Global Facility for Disaster Reduction and Recovery. 2014. Available online: https://www.preventionweb.net/quick/43547 (accessed on 20 August 2023).
35. Romão, X.; Paupério, E.; Pereira, N. A framework for the simplified risk analysis of cultural heritage assets. *J. Cult. Herit.* **2016**, *20*, 696–708. [CrossRef]
36. Australia ICOMOS. The Burra Charter. The Australia ICOMOS Charter for Places of Cultural Significance. Burn-Wood: Australia ICOMOS. 1999. Available online: https://australia.icomos.org/publications/burra-charter-practice-notes/burra-charter-archival-documents/ (accessed on 20 August 2023).
37. Cunha Ferreira, T.; Mendonça, H.; Lourenço, P.; Póvoas, R.F.; Tostões, A.; Valença, J.; Costa, H.; Júlio, E. Reuse and Conservation of Built Heritage in Exposed Concrete: Recent Intervention by Álvaro Siza (2018–2021). In *Built Heritage Sustainable Reuse. Building Pathology and Rehabilitation*; Varum, H., Cunha Ferreira, T., Eds.; Springer: Cham, Switzerland, 2023; Volume 26. [CrossRef]
38. Schueremans, L.; van Gemert, D.; Giessler, S. Chloride penetration in RC-structures in marine environment-Long term assessment of a preventive hydrophobic treatment. *Constr. Build. Mater.* **2007**, *21*, 1238–1249. [CrossRef]
39. Liu, J.; Ou, G.; Qiu, Q.; Xing, F.; Tang, K.; Zeng, J. Atmospheric chloride deposition in field concrete at coastal region. *Constr. Build. Mater.* **2018**, *190*, 1015–1022. [CrossRef]
40. Santos, F.D.; Miranda, P. (Eds.) *Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação*; Projecto SIAM II; Gradiva: Lisboa, Portugal, 2006.
41. Tavares, A.O.; Barros, J.L.; Freire, P.; Santos, P.P.; Perdiz, L.; Fortunato, A.B. A coastal flooding database from 1980 to 2018 for the continental Portuguese coastal zone. *Appl. Geogr.* **2021**, *135*, 102534. [CrossRef]
42. Antunes, C.; Rocha, C.; Catita, C. Coastal flood assessment due to sea level rise and extreme storm events: A case study of the atlantic coast of Portugal's mainland. *Geosciences* **2019**, *9*, 239. [CrossRef]
43. IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Core Writing Team, Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014.
44. IPCC. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, NY, USA, 2021.
45. Antunes, C. Assessment of Sea Level Rise at West Coast of Portugal Mainland and Its Projection for the 21st Century. *J. Mar. Sci. Eng. Int.* **2019**, *7*, 61. [CrossRef]
46. Lindsey, R. Climate Change: Atmospheric Carbon Dioxide. 2023. Available online: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide (accessed on 20 August 2023).
47. IPCC. The Carbon Cycle and Atmospheric Carbon Dioxide. In *Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, NY, USA, 2001.
48. Gilabert Campos, M.A.; Castellano Pulido, F.J.; García Píriz, T. Arquitecturas del baño frente a la subida de la cota cero. In Proceedings of the XIII CTV 2019 Proceedings: XIII International Conference on Virtual City and Territory: "Challenges and Paradigms of the Contemporary City": UPC, Barcelona, Spain, 2–4 October 2019; CPSV: Barcelona, Spain, 2019; p. 8482. [CrossRef]
49. Costa, A.; Appleton, J. Concrete carbonation and chloride penetration in a marine environment. *Concr. Sci. Eng.* **2001**, *3*, 241–249.
50. CMM. Municipal Plan for Civil Protection Emergency. Câmara Municipal de Matosinhos. 2011. Available online: https://www.cm-matosinhos.pt/cmmatosinhos2020/uploads/writer_file/document/30312/pme_net.pdf (accessed on 20 August 2023). (In Portuguese)
51. Spennemann, D.H.R.; Look, D.W. From conflict to dialogue, from dialogue to cooperation, from cooperation to preservation. In *Disaster Management Programs for Historic Sites*; Spennemann, D.R., Look, D.W., Eds.; Association for Preservation Technology, Western Chapter: San Francisco, CA, USA, 1998.

52. UNESCO. *Managing Disaster Risks for World Heritage. World Heritage Resource Manual*; UNESCO: Paris, France, 2010.
53. Court, S.; Jo, E.; Mackay, R.; Murai, M.; Therivel, R. *Guidance and Toolkit for Impact Assessments in a World Heritage Context*. Manual. Paris/Rome/Charenton-le-Pont/Gland: UNESCO/ICCROM/ICOMOS/IUCN. 2022. Available online: https://whc.unesco.org/en/guidance-toolkit-impact-assessments/ (accessed on 10 January 2023).
54. Feilden, B.; Jokkilehto, J. *Management Guidelines for World Cultural Heritage Sites*; ICCROM: Rome, Italy, 1998.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.