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Research Article

Prioritizing Heritage Building Maintenance: A Fuzzy Model Approach for Arc De Berà, Spain

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ABSTRACT

The "Art-Risk 3.0" research project has developed a new tool to address the challenges faced in maintaining and preserving cultural heritage. This tool aims to evaluate the functional operational age and life cycle of heritage buildings in the Arc de Berà area in Tarragona, Catalonia, Spain, with the goal of promoting preventive conservation through a multidisciplinary approach. The tool considers various factors that contribute to the condition of heritage buildings, including structural stability, material decay, environmental risks, and usage patterns. By employing a fuzzy model, it provides an assessment of the building's condition in historical sites. One of the key features of the Art-Risk tool is its ability to prioritize intervention among different case studies within a specific urban context. It generates three output results: vulnerability, risk, and functionality index. The vulnerability value indicates the level of vulnerability of a building, with lower values suggesting better structural stability and resilience against potential hazards. The risk value signifies the level of risk associated with a building, with lower values indicating a reduced likelihood of damage or deterioration. The functionality index reflects the operational condition and suitability of a building for its intended use, with higher values indicating better functionality and operational performance, by considering these diverse valuations, stakeholders and conservation plan managers can effectively establish priorities for intervention. Buildings with higher vulnerability, risk, or lower functionality index scores are given higher priority for intervention. This approach ensures that limited resources are allocated to the buildings that require immediate attention, maximizing the impact of conservation efforts. Art-Risk 3.0 model incorporates 19 input variables, with five variables automatically assigned based on the building's geographic location. Users are required to provide valid geographical coordinates and the remaining 14 associated values to obtain an accurate assessment of the building's condition.

Keywords: Fuzzy Model, Arc De Berà, Art-Risk 3.0, Artificial Intelligence, Digital Heritage, Risk Management.

INTRODUCTION

Historical buildings and Archaeological sites are buildings or structures that have historic value, and cultural values conveyed to future generations. Cultural heritage buildings are treasures, not just because of their architectural, aesthetic, and scientific values, but also because of their inherent tangible and intangible cultural values. They impose the past into the present and keep developing culture. Therefore, conserving cultural heritage helps development to be more sustainable (Ahmad, Rahmanto, Pratama, & Borman, 2021; Colace et al., 2021), this reality imposes work on preserving it and dealing with it well. Heritage is also one of the most important mechanisms adopted by the countries of the world to attract tourism and thus activate the economic cycle. On this basis, many countries of the world have worked to provide effective protection for this heritage, World Heritage in danger has suffered from armed conflict and war, earthquakes and other natural disasters, pollution, uncontrolled urbanization, and unchecked tourist development pose major problems for heritage preservation organizations (UNESCO, 2020; Haddad, Fakhoury, & Sakr, 2021). By adhering to the recommendations of the conventions and seminars that were held specifically to put forward modern strategies aimed at preserving the common heritage of humanity (Silberman, 2008), All Dangers have been identified as the most dangerous factors affecting the integrity and value of cultural heritage, referring to specific and proven imminent threats, or potential when cultural heritage is faced with cultural which could have negative effects on its World Heritage values (Van Balen, 2015). At heritage sites, preventive conservation requires multidisciplinary knowledge of historical heritage diagnosis, and functional operational age of heritage buildings (Prieto, Macías-Bernal, Chávez, & Alejandre, 2017), by using an innovative fuzzy inference system that can quantify the vulnerabilities and risks that face World Heritage Sites, their functional service life (Prieto, Macías-Bernal, Silva, & Ortiz, 2019). The fuzzy model has been widely applied as a support tool for decision-making processes and performance evaluation the preventive conservation of heritage buildings came about through the conservation of cultural heritage, and specifically in the decision-making support for the restoration and conservation of heritage buildings (Nadkarni & Puthuvayi, 2020; Zimmermann, 2010). Preventive conservation involves "all measures and actions aimed at avoiding and minimizing future deterioration or loss. They are carried out within the context or on the surroundings of an item, but more often a group of items, whatever their age and condition. These measures and actions are indirect - they do not interfere with the materials and structures of the items. They do not modify their appearance." (ICOM-CC). The preventive maintenance of historic buildings is a critical matter for sustainable construction considering three demands social, economic, and cultural values, the definition of preventive conservation of buildings by Balen (Van Balen, 2015; Mahmoud, 2021), is actions aimed at avoiding and minimizing future deterioration or loss, the condition assessments, early deterioration detection, and planned interventions to minimize damage. Digital heritage management is a new technology in designing and implementing effective preventive preservation strategies and programs that can manage data from sites by professional experts (Rahaman, 2020; Rahaman & Kiang, 2017).

In addition to this, for a literature survey on research that brings a fuzzy approach to incomplete data sets using Fuzzy Archaeological Data (Tuncalı Yaman, 2019), data Provenance of Archaeological Temporal Information in the Presence of Uncertainty (Migliorini, Quintarelli, & Belussi, 2022) without reference to stratigraphic data (Tirpáková, Vojteková, Vojtek, & Vlkolinská, 2021) and digital restoration by introducing fuzzy analytics to comprehensively evaluate the restoration effect (Liu et al., 2022). The degradation of heritage buildings is an important issue affected by different parameters that contain a certain degree of uncertainty, the evaluation of the functional service life of cultural heritage is a complex subject due to vulnerabilities and hazards (Ortiz & Ortiz, 2016; Shan, Chen, Zhai, & Du, 2022). Natural stone located in urban areas undergoes biological degradation, the fungi, algae, bacteria, lichens, and various elements from the environment air, soil, etc., in addition to the organisms themselves inhabiting the stone surface interacting with the underlying rock, which leads to weathering on the stone surface (Sazanova et al., 2020). In this sense, the preservation of cultural heritage requires new approaches, methods, and strategies for preserving it over time.

Figure 1. Degradation of Arch De Bera Stone

Therefore, in this study, to deal with the uncertainty and vagueness associated with the evaluation of the functional condition of the Arc de Berà heritage site, the digital management of heritage buildings' preventive conservation requires a joint vision of the multidisciplinary knowledge of different vulnerabilities and risks in heritage diagnosis, the fuzzy logic principles established by Zadeh (1965) were used as a reference.

MATERIALS AND METHODS

The Art-Risk 3.0 project "Artificial intelligence applied to preventive conservation of heritage buildings" is a new computerized tool for conserving heritage in urban centres based on models of artificial intelligence. For the restoration and rehabilitation, vulnerability and risk analysis, the adoption of scientific criteria, and regional policies for the planning and management of maintenance actions, thus minimizing the risks of losses of cultural assets.

Creating this new method of vulnerability and risk analysis for monuments necessitates the participation of a multidisciplinary team specializing in heritage protection and conservation.

The Art-Risk 3.0 team consists of researchers and professionals in many disciplines. The modernity of this challenge lies in its approach and results, this project will develop a new predictive model based on fuzzy logic, which will include assessing environmental risks and climate change, building use levels, and structural risks, as well as historical data from monuments' lives. This new tool will enable scientific decision-making, reducing the risk of cultural asset losses, and assessing the degree of vulnerability of the Monument over time. This information can be applied by different stakeholders and promote an effective maintenance approach to cultural heritage.

Case Study Analysis (Arc de Berà)

This is the most well-known Roman monumental arch in Catalonia, built in the 1st century B.C. in the times of Emperor Augustus. It is an arch with a single opening, made up of two podiums on which two large single pillars rise up, joined by a semi-circular arch. The Arc de Berà is a Roman monument at Rode de Berà (Tarragona) built at the end of the first century BC (Dupré, 1994), Approximate age: 1-2 century AD. In recent centuries it has been restored on various occasions: in 1788, 1840, 1936, and, most recently, in 1994-1998.

Figure 2. Arch De Bera Location in North- East of the City of Tarragona, Catalonia, Spain

Arc de Berà is a triumphal arch some 20 km northeast of the city of Tarragona Catalonia, Spain as shown in Figure 2. This monument is part of the Archaeological Ensemble of Tarraco, which was added the UNESCO's list of World Heritage Sites in 2000. It is located on the Via Augusta, now the N-340 road.

Arc de Berà

Intangible value

UNESCO and cultural heritage defined "intangible value" as the non-physical aspects of heritage that are deeply rooted in social practices, customs, rituals, knowledge, festive events, and skills. It encompasses the living expressions and traditions that are passed down from generation to generation and play a significant role in shaping a community's identity and cultural diversity.

In 2003, UNESCO adopted the Convention for the Safeguarding of Intangible Cultural Heritage, which defines intangible cultural heritage as:

"The practices, representations, expressions, knowledge, skills - as well as the instruments, objects, artefacts, and cultural spaces associated therewith – that communities, groups, and, in some cases, individuals recognize as part of their cultural heritage. This intangible cultural heritage, transmitted from generation to generation, is constantly recreated by communities and groups in response to their environment, their interaction with nature, and their history, and provides them with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity."

The Arch of Berà was erected at the end of the 1st century BC as homage to Augustus and in memory of the person who paid for it to be built, Lucius Licinius Sura. Over time its image has been used on book covers, advertising posters, and tourist souvenirs.

Although this type of construction is often known as a triumphal arch, they were not always built to commemorate military victories, and therefore it is more accurate to use the term honorary arch, these types of arches had a sacred value and were built in important locations, such as the borders between two properties, or to mark the existence of a bridge or a river, etc.

Lucius Licinius Sura was a Roman official during the second half of the first century – the beginning of the second century, the consul of 102 and 107 years. He came from the province, had a brilliant career, and took a number of positions under the emperors Domitian, Nerva, and Trajan. Two thousand years after it was built, this honorary arch is still one of the most evocative symbols of Roman culture and everything the Romans wished to communicate to the societies of the future.

Tangible value

Arch de Bera is an object of classical Roman architecture, located on the Via Augusta road, about 20 km northeast of Tarragona (now the N-340 highway). The arch is built from local limestone (Figure 3) and brought from a neighbouring quarry (today it is the town of Roda de Bera). The Arch of Berà was built straddling the Via Augusta at the end of the 1st century BC, although the arch we see today is not exactly the same as the Romans would have seen.

Over the centuries, numerous modifications have been made to the monument (Figure 4). Apart from the deterioration caused by the passing of time (Gurrera, Raventos, Bou, & Prada Perez, 1994), some ill-conceived restoration projects have seriously endangered its integrity. The arch contains a laudatory inscription whose dedication makes reference to Lucius Licinius Sura, a member of Tarraco's elite, originally from Celsa (Aragon), who relied on imperial support to build it. An epigraphic text is situated today above the architrave of the north face of the arch. Its original placement was actually on the opposite face. It is possible to date the construction to between 15 B.C. and 5 A.D.

Figure 3. Limestone Details in Arch of Berà

Throughout its history, the Berà Arch has been repeatedly plundered, reformed, and transformed, which has modified its original physiognomy. In 1840, Queen Isabel II's scheduled visit to Tarragona, accompanied by General Espartero, led to restoring the monument. Also in 1930 highway required the route diverted and go around the arch, as we can see today.

Figure 4. The Current State of Arch De Bera

The monument we see today as we drive along the main N-340 road is the result of the most recent restoration in 1998, a meticulous task of research carried out under the supervision of the archaeologist Xavier Dupré (1994). The arch is missing its upper body on which there was probably a group of sculptures representing Augustus and other members of his family.

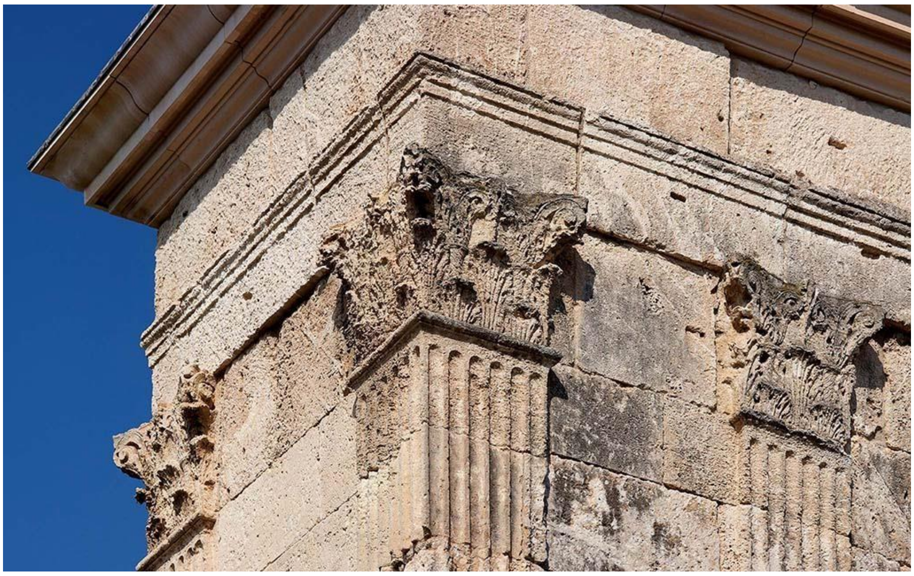


Figure 5. The Architecture of Arch De Bera

This is an arch with a single opening, with sides built on smooth baseboards and walls decorated with grooved Corinthian pilasters (Figure 5), it measures 12.30 meters in height, 2.4 meters in width, and 12 meters in length. It is built with local stones and is an arch with a single opening made up of two podiums on which two large pillars rise up and are united by a semi-circular arch. On the pillars, eight pilasters are attached with Corinthian letters, on which is an altarpiece on which is an architrave and frieze with the previously mentioned inscription.

FUNCTIONAL SERVICE LIFE MODEL (ART-RISK 3.0)

Fuzzy logic, proposed by Zadeh (1965), is an approach to computing based on degrees of truth, it is a strong instrument used in the modelling reality phenomena, and a risk management tool as a systematic approach to setting the best action under uncertainty by identifying, assessing, and understanding risk issues, for the preservation of the physical and human assets. Fuzzy logic involves conceptualizing the vagueness and uncertainty of complex phenomena, such as the degradation of heritage buildings, into numerical models and crisp quantifiable parameters. Fuzzy logic systems can be adopted for the definition of effective planning of maintenance activities in buildings, providing pragmatic solutions (Prieto et al., 2019). The project of ART-RISK 3.0 project, suggests a functional service life cycle model, based on fuzzy logic principles, to prioritize maintenance actions in heritage buildings and monuments.

The fuzzy tool (ART-RISK 3.0) is a computerized tool fully programmed in Java, so it can be executed in most computer systems. Use for the preventive conservation of heritage in urban centres based on artificial intelligence models (Jigyasu & Arora, 2014). With which the vision that can be applied includes the heritage, urban planning, architectural and cultural value, the analysis of the environmental surroundings and the socio-demographic situation of the work.

All this allows for decision-making based on scientific criteria and thus minimizes the risk of loss of heritage elements. This tool allows the approximate reproduction of human reasoning and the existing relationships between the monument's vulnerability factors, risk factors, and historical parameters through the theory of diffuse sets.

The fuzzy adapted model is supported in the third version of Art-Risk 3.0 has 19 input variables. Five of these variables are automatically assigned from the geographic location of the building (www.upo.es/investiga/art-risk-en). The user must enter valid geographical coordinates of the building in WGS84 format (EPSG: 4326). This means that the user must enter the other 14 values of remaining entries associated with the building you want to value, four related to the buildings ' vulnerabilities and six associated with the risks (static-structural and anthropic risks) (Table 1).

To initiate the analysis using the Art-Risk 3.0 software, the analysis is presented with a screen displaying 19 numerical input variables, each ranging from 1.0 (most favourable value) to 5.0 (most unfavourable value)(Figure 8). Additionally, the geographical coordinates of the building under study were entered. These coordinates are in WGS84 (EPSG:4326) format, commonly used in OpenStreetMaps and GoogleMaps. The latitude and longitude coordinates are expressed in decimal degrees, representing the location of the building on a map of Spain.

Upon selecting certain variables, such as Geotechnics, Medium precipitation, Rain erosion by rainfall, Thermal stress, Frost, Seismic hazard, and Flood hazard, the corresponding values will be automatically assigned by the system (Figure 7). These variables, referred to as 'automatic variables,' cannot be manually edited by the user. The remaining variables must be manually entered by the user, with values ranging between 1.0 and 5.0. The Art-Risk 3.0 software supports a total of 21 variables that can be manually entered. Table 1 provides the qualitative and quantitative definitions of each variable, along with brief descriptions to aid in their understanding and assessment.

Vulnerability

1. Geotechnics: Building conditions are classified based on five criteria related to the terrain in each area, documentation from the Spanish Geological and Mining Institute is used, and the construction conditions are established using lithological, geomorphological, hydrological, and geotechnical factors.

2. Built environment: Five criteria categorize the organic growth, extensions, substitutions, aggregations, and divisions that have influenced the state of the partition walls of heritage buildings, potentially leading to accessibility issues and easements.

3. Constructive system: The number of building systems is considered, including structural, façade, walls, roofs, interior layout, and finishes, The more complex and heterogeneous the systems, the higher the vulnerability.

4. Changes in population: Population fluctuations impact the number of individuals associated with the property, Declining populations may result in resource scarcity and abandonment of monuments, leading to building deterioration.

5. Heritage Value: The degree of legal protection and/or social, cultural, and liturgical significance of the building determines its heritage value.

6. Value of movable assets: The contents of the property, based on legal protection or social, cultural, and liturgical significance, are classified into five criteria.

7. Occupancy: The degree of occupancy and the level and nature of activities conducted within the building are considered using five classification criteria.

8. Maintenance: Scheduled actions that impact the building's state of conservation, including the presence of permanent technical staff, are assessed using five criteria.

9. Roof design: The ease of water drainage on roofs, influenced by constructional and geometrical

modifications over time, is classified into five criteria. The vulnerability of the building depends on the speed and simplicity of roof water drainage.

10. Conservation: The different parts of the building (facade, party walls, roofs, foundations, structure, installations, accessibility, etc.) and their level of conservation are jointly evaluated using five classification criteria.

Static-Structural Hazards

1. Ventilation: Natural ventilation classifies Five criteria based on the presence of windows, doors, or other systems on all facades that allow daily ventilation, with natural cross ventilation being the ideal condition.

2. Facilities: Water supply and sanitation, electricity, and active fire protection: Five criteria based on the extent to which the facilities meet current standards, including visual inspections.

3. Fire risk: Likelihood of fire occurrence and intensity of spread: Five criteria considering factors such as the presence of wooden structures, altars, movable goods, and flammable materials like curtains or tapestries.

4. Overload: Use of spaces, furniture, equipment, and changes in static loads: Five criteria based on the impact of space utilization, furniture, and equipment on the durability of the building, including changes in use over time.

5. Structural modifications: Extensions or reforms that alter the initial load: Five criteria based on modifications that have partially or substantially changed the original load for which the building was constructed, including extensions and unplanned structural changes.

Environmental Threats

1. Medium precipitation: Amount of rainfall per unit area: Five criteria based on rainfall data, considering the Iberian Climate Atlas and the recommendations of the World Health Organization.

2. Erosion by rainfall: Rainfall intensity and erosion: Five criteria based on rainfall intensity, using the torrential rain index provided by the Ministry of Public Works.

3. Thermal stress: Temperature variations in a short period: Five criteria based on average daily temperature variations, obtained from the annual average of extreme daily temperatures.

4. Frost: Freezing temperatures: Five criteria based on frost risk, using data from the Spanish State Meteorological Agency on frost and hours of cold.

5. Natural hazards: Seismic hazard: Probability of earthquakes: Map based on the Seismic Resistant Construction Standard of the Ministry of Public Works.

6. Flood hazard: Water overflowing from rivers, torrents, etc.: Map based on data from the National Flood Mapping System of the Ministry of Agriculture and Fisheries, Food and Environment.

The classification criteria for each variable help assess the risks associated with static-structural hazards and environmental threats to the building under consideration.

Table 1. Input Factor and Description of the Valuation of the Fuzzy Model (ART-RISK 3.0) Variable, Adapted to the Specific Context of the Study (Manual ART-RISK 3.0 Tool, 2022)

Vulnerability and risk	**ID**	**Input Variable**	**Quantitative Value (1-5)**	**General descriptions factors of The Functional Service Life Model (ART-RISK 3.0)**
Vulnerability	AR 1	Geotechnics	(1.0/2.0/3.0/4.0/5.0)	Evaluation of geotechnical conditions in a specific location using GIs maps
	AR 2	Built environment	(1.0/2.0/3.0/4.0/5.0)	The complexity of the built environment within a specific location.
	AR 14	Overloads in use	(1.0/2.0/3.0/4.0/5.0)	Overload situations of the building (people and furniture), which is produced using different areas.
	AR 9	Design of covers	(1.0/2.0/3.0/4.0/5.0)	Determine the water evacuation capability of the covers
	AR 15	Structural changes	(1.0/2.0/3.0/4.0/5.0)	The assessment of the structural modifications that have been made to a building or structure, this assessment is conducted by experts to evaluate the nature and extent of the changes.
Structural risk	AR 3	Construction system	(1.0/2.0/3.0/4.0/5.0)	The construction system used in a particular building or structure is related to the construction

Vulnerability and risk	**ID**	**Input Variable**	**Quantitative Value (1-5)**	**General descriptions factors of The Functional Service Life Model (ART-RISK 3.0)**
				methods and materials employed.
	AR 6	Movable value	(1.0/2.0/3.0/4.0/5.0)	The degree of legal protection, social, and cultural of equipment is evaluated.
	AR 8	Maintenance	(1.0/2.0/3.0/4.0/5.0)	The evaluation of the maintenance status of a building or facility assesses the presence of a maintenance plan, scheduled activities, and staff responsible for maintenance tasks.
	AR 12	Facilities	(1.0/2.0/3.0/4.0/5.0)	Evaluation of the condition and compliance of various installations within a building or structure, this assessment is conducted by experts to determine the level of conformity with standards and the operational status of the facilities.
	AR 10	Preservation	(1.0/2.0/3.0/4.0/5.0)	The assessment of the preservation status of a building or structure involves expert valuation to determine the level of preservation needed for the asset.
Atmospheric risks	AR 13	Fire risk	(1.0/2.0/3.0/4.0/5.0)	The evaluation of the fire risk within a building or structure, assessment is conducted by experts to determine the level of fire risk based on the structure's combustibility and the amount of potential fuel load present.
	AR 16	Average Precipitation	(1.0/2.0/3.0/4.0/5.0)	Average annual rainfall, data from the Spanish meteorological agency.
	AR 17	Rain erosion	(1.0/2.0/3.0/4.0/5.0)	The rainfall intensity coefficient has been taken into account, relating the precipitation falling in one hour to the fall during 24 hours.
	AR 19	Frost	(1.0/2.0/3.0/4.0/5.0)	Annual frost days, data from the Spanish meteorological agency.
	AR 20	Earthquake risk	(1.0/2.0/3.0/4.0/5.0)	Acceleration values, obtained from the seismic hazard map of the seismic-resistant standard ncse-02.
	AR 21	Flood risk	(1.0/2.0/3.0/4.0/5.0)	the values have been defined according to the return period of floods in both riverbeds and coastal environments
Anthropic risks	AR 18	Thermal stress, temperature variation	(1.0/2.0/3.0/4.0/5.0)	The maximum and minimum half temperature in the year.
	AR 7	Occupation	(1.0/2.0/3.0/4.0/5.0)	Assessment of the level of occupation or activity within a building, to determine the intensity of activities taking place inside the building.
	AR 4	Population change	(1.0/2.0/3.0/4.0/5.0)	Population change in a specific area or location is the percentage of population growth or decline within a given timeframe.
	AR 5	Asset value	(1.0/2.0/3.0/4.0/5.0)	Assessment of the value of an asset, such as a building or structure, based on expert valuation, various factors related to the asset's characteristics and historical or artistic significance.
	AR 11	Ventilation	(1.0/2.0/3.0/4.0/5.0)	The assessment of the ventilation conditions within a building or structure involves expert valuation to determine the level of natural cross-ventilation present in different spaces.

Rules applied from the fuzzy model to the input variables generate three levels of new intermediate variables. The full hierarchical structure of the fuzzy model is shown in Table 2; it is the interrelation of the variables developed in the different levels of the fuzzy model.

As can be seen in Table 2, the first level of intermediate fuzzy variables on the hierarchical structure is the next one. For Vulnerability A, Vulnerability B, Structural Risk A, Static-Structural Risk B, and Anthropogenic risks, these variables are generated by inference rules based on the entry variables. In this sense Vulnerability A, Vulnerability B, and Anthropogenic risk all arrange Strength in the second rule level. Moreover, Vulnerability A, Structural Risk A, and Structural Risk B generate the Static- Structural Risk output.

Finally, the third level, made up of Strength, Static Structural Risk, and Atmospheric Risk, generates the next Durability output, and through this intermediate output, the level of functionality is obtained as the final output (Prieto et al., 2017; Prieto, Macías-Bernal, Chávez, & Alejandre, 2015; Prieto et al., 2019).

The Art-Risk 3.0 software is a freely available tool that integrates both manual user input and automatic data output based on geographic location using Geographic Information Systems (GIS) technology. The input data is categorized into groups, as outlined in Table 1, which is based on two fundamental concepts: hazard and vulnerability. Hazards can be of natural or human-induced origin, such as earthquakes or armed conflicts. Vulnerability refers to the susceptibility or responsiveness of cultural property to these hazards, indicating the inherent weaknesses of the cultural asset. Additionally, the service life of the building is influenced by the interplay of hazards, vulnerability, and management practices related to maintenance.

To combine these variables, the software employs a formula depicted in Figure 2. The determination of inference relationships within this formula is based on the DELPHI model. Prior to utilizing the software, a preliminary inspection visit is conducted on the buildings under study, and the resulting analysis and assessment are entered into the tool.

Table 2. Hierarchical Structure of the ART-RISK3.0 Fuzzy Model

AR 1	**Geotechnics**	Vulnerability B	Durability	Output: Functional service life model adapted (ART- RISK3)
AR 2	Built environment			
AR 3	Construction system			
AR 8	Maintenance			
AR 5	Asset value	Anthropogenic risks		
AR 6	Movable value			
AR 4	Population change			
AR 7	Occupation			
AR 10	Preservation	Vulnerability A		
AR 9	Design of covers			
AR 11	Ventilation	Structural risks A		
AR 12	Facilities			
AR 13	Fire risk			
AR 14	Overloads in use			
AR 15	Structural changes			
AR 16	Average Precipitation	Structural risks B		
AR 17	Rain erosion			
AR 18	Thermal stress, temperature variation			
AR 19	Frost	Atmospheric structural risks		
AR 20	Earthquake risk			
AR 21	Flood risk			

Table 2 provides hierarchical priorities for each of the output data values obtained in the 'Results' section. The interpretation of each value and the corresponding actions are as follows(Figure 9):

1. Vulnerability assessment of the building:

- Low Vulnerability (<35): The building is in excellent condition.
- Medium Vulnerability (75-35): The building has certain pathologies and conditions that have been studied.
- High Vulnerability (>75): The building is in a poor state of conservation.

2. Assessment of identified environmental hazards affecting preventive conservation:

- Low Hazard (<35): Acceptable level of environmental hazards.
- Medium Hazard (75-35): Medium level for external environmental hazards.
- High Hazard (>75): High level of external environmental hazards.

3. Functionality index assessment:

- High functional life (>75): Optimum conditions of functionality.
- Medium functional life (75-35): Periodic inspections are required to ensure an acceptable level of functionality by specialist technicians.
- Low functional life (<35): Unacceptable level of functionality.

The overall assessment of the building was made by comparing the values obtained for each variable. Based on these interpretations, the hierarchical priorities for conservation needs are determined. Here is a priority order:

1. High Vulnerability (>75) and/or High Hazard (>75): Buildings with both high vulnerability and high hazard levels are given the highest priority for conservation. These buildings are in a poor state of conservation and face significant external environmental risks.

2. High Vulnerability (>75): Buildings with high vulnerability but lower hazard levels are the next priority. They require urgent attention due to their poor state of conservation.

3. High Hazard (>75): Buildings with high environmental hazard levels but lower vulnerability should also be prioritized. Although their condition may be relatively better, the external environmental risks pose a significant threat.

4. Medium Vulnerability (75-35): Buildings with medium vulnerability levels studied to address the identified pathologies and conditions. They require further investigation and tailored conservation strategies.

5. Medium Hazard (75-35): Buildings with medium environmental hazard levels require attention to mitigate external risks and ensure preventive conservation measures.

6. Low Vulnerability (<35): Buildings with low vulnerability levels are in excellent condition and considered for periodic inspections and maintenance to sustain their good state of conservation.

7. Low Hazard (<35): Buildings with low environmental hazard levels have an acceptable level of risk. They still monitored and maintained to preserve their condition.

By following this hierarchical priority order, stakeholders effectively allocate resources and address the conservation needs of the evaluated buildings, ensuring the maximum impact of conservation efforts.

RESULTS AND DISCUSSIONS

Cultural heritage Archeological sites and monuments are threatened by humans or nature, decision-makers need to prioritize threats, information regarding the risk status, and priorities in which intervention for conserving it (Dhonju, Xiao, Mills, & Sarhosis, 2018; Hategekimana et al., 2018).

The ART-RISK 3.0 methods are focused on the functional degradation condition with a focus on tangibility and intangibility of cultural heritage, to choose suitable preventive maintenance, to reduce the buildings ' degradation functional with time, and thus reducing the risks and Vulnerability associated with it and sustainable conservation (Agapiou, Lysandrou, Themistocleous, & Hadjimitsis, 2016; Kravari, Emmanouloudis, Korka, & Vlachopoulou, 2022). ART- RISK 3.0 is an engineering method based on fuzzy logic (artificial intelligence), by merging geographical data according to the importance given to the environmental factors (natural and human), which aids public and private authorities in making decisions regarding the preservation of cultural heritage (Moreno et al., 2022).

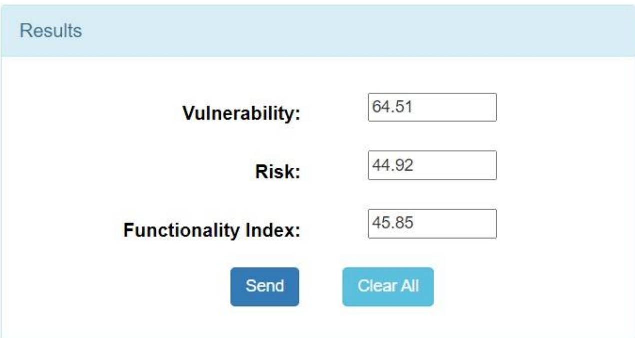


Figure 6. Output Model ART-RISK 3.0

The results of the functional service life model based on visual inspection of the function, along with the quantification and alteration of the results into the proposed fuzzy inference system, are presented. This model provides priorities for preventive conservation activities in homogeneous groups of heritage buildings, classifies sets of buildings with homogeneous construction features, and ranks them using the Priority. It also provides Priority to the vulnerability and risk conditions for interventions.

Table 2 demonstrates the application of the proposed model for analyzing the functional condition of the Arc de Berà. A functional degradation condition scale with three levels (A, B, or C) was established. Condition A represents an arch with an acceptable functionality state, Condition B indicates that the arch requires periodical inspections to maintain minimal acceptable functional conditions, and Condition C suggests that the arch does not guarantee an adequate functionality level based on the methodology (Silva et al., 2016).

Applying the proposed model to the Arc de Berà, several conclusions can be drawn. The Arc de Berà, located near Roda de Berà in Catalonia, Spain, is a historical and social symbol of the city. Throughout its history, the arch has undergone repeated plundering, reformation, and transformation, altering its original appearance. Prior to intervention in 1998, the arch was practically abandoned, showing signs of dirt and debris deposition, staining or colour changes, and some detachment or wearing. Currently, urban pressure and factors such as parasitic vegetation, stone rock degradation, loss of integrity, material loss, biological growth, efflorescence, and stains pose significant threats to the arch's integrity and value.

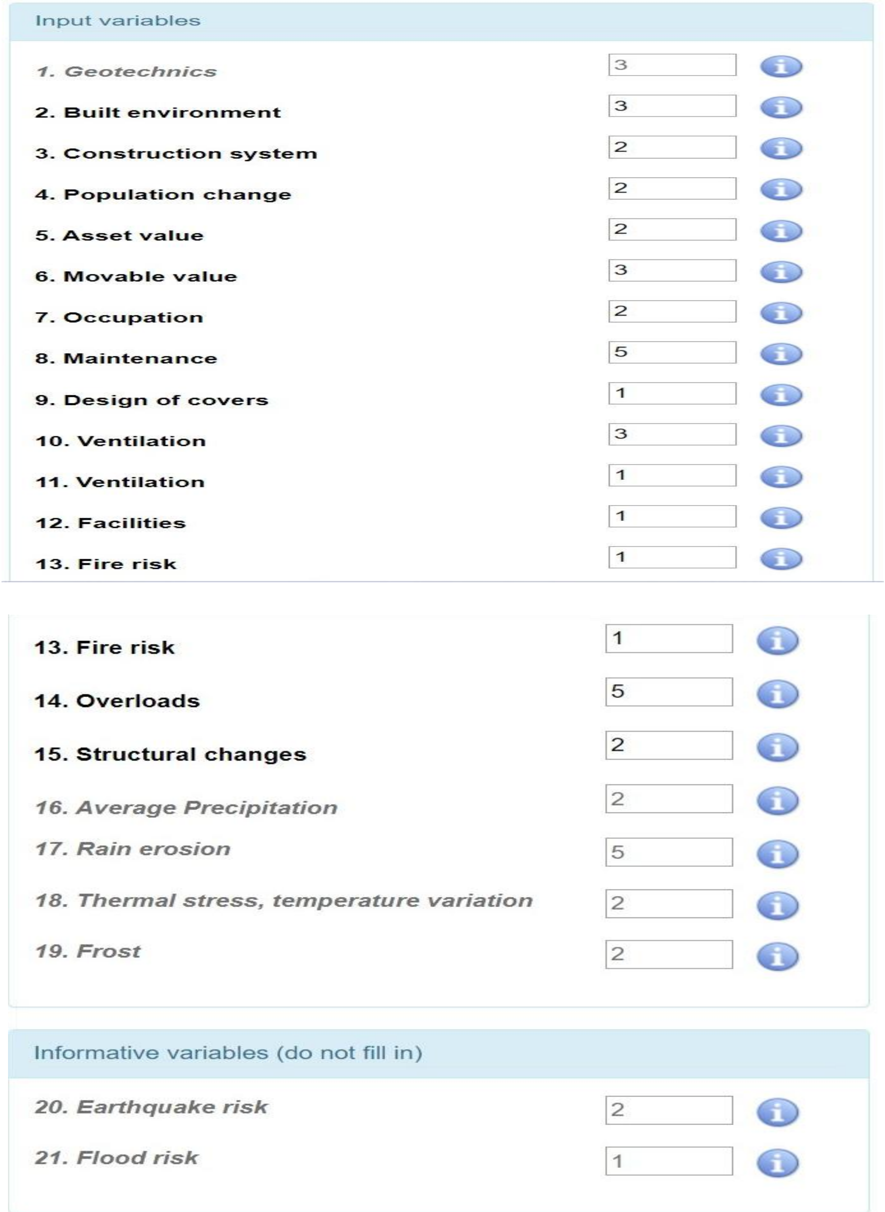
According to the proposed model (ART-RISK 3.0), the functionality condition of the Arc de Berà after intervention in 1998 was around 45.85 points (Figure 6), indicating that it requires periodical inspections to maintain minimal acceptable functional conditions.

This fuzzy model represents a valuable contribution to implementing new approaches for preventive maintenance actions in historical cities, aiming for sustainable urban development based on functional criteria (Ortiz et al., 2016). Furthermore, the ART-RISK 3.0 model allows non-specialized users to evaluate the functional degradation condition of cultural heritage buildings. With appropriate adaptations and the inclusion of more results into a GIS (Geographic Information System), the proposed model can be easily implemented in arches and other monuments, both within and outside of Spain.

To ensure successful future preventive maintenance actions, it is crucial to analyze previous maintenance works, and their effects on the functional performance of buildings, and assess the functional state after prevention and conservation activities in heritage assets.

The analysis of previous maintenance works is essential for the success of future preventive maintenance actions, by understanding the impact of past interventions on the functional performance of buildings. This includes evaluating the effectiveness of different restoration techniques, materials used, and maintenance strategies employed. In addition to examining past maintenance works, it is crucial to assess the functional state of heritage assets after prevention and conservation activities. This allows for the evaluation of the long-term effectiveness of the interventions and provides valuable feedback for future decision-making processes. By monitoring and analyzing the functional performance of heritage buildings over time, it becomes possible to refine and improve preventive maintenance strategies. The application of the proposed model, such as ART-RISK 3.0, not only enables the assessment of functional degradation conditions but also facilitates the identification of areas requiring further attention and intervention. By incorporating the model within a GIS, it becomes even more powerful, allowing for spatial analysis and visualization of the functional condition of multiple arches and monuments. The benefits of this approach extend beyond Spain, as the model can be adapted and implemented in historical cities worldwide. By providing a systematic and standardized framework for evaluating functional degradation conditions, decision-makers, architects, and heritage professionals can make informed decisions regarding preventive maintenance actions. This promotes the sustainable preservation of cultural heritage, ensuring the long-term viability and value of these assets. The integration of the functional service life model, fuzzy inference systems, and GIS technology represents a significant advancement in the field of heritage conservation. By combining expert knowledge, visual inspections, and quantitative analysis, this approach provides a comprehensive understanding of the functional condition of heritage buildings. It empowers stakeholders to prioritize conservation efforts, allocate resources effectively, and promote the sustainable development of historical cities.


Coordinates of the building
Latitude
41.173443
Longitude
1.4689962
Automatic input variables 1, and 16 to 21, correctly assigned
Select coordinates
Validate coordinates


Input variables
1. Geotechnics 3
2. Built environment 3
3. Construction system 2
4. Population change 2
5. Asset value 2
6. Movable value 3
7. Occupation 2
8. Maintenance 5
9. Design of covers 1
10. Ventilation 3
11. Ventilation 1
12. Facilities 1
13. Fire risk 1
13. Fire risk 1
14. Overloads 5
15. Structural changes 2
16. Average Precipitation 2
17. Rain erosion 5
18. Thermal stress, temperature variation 2
19. Frost 2
Informative variables (do not fill in)
20. Earthquake risk 2
21. Flood risk 1

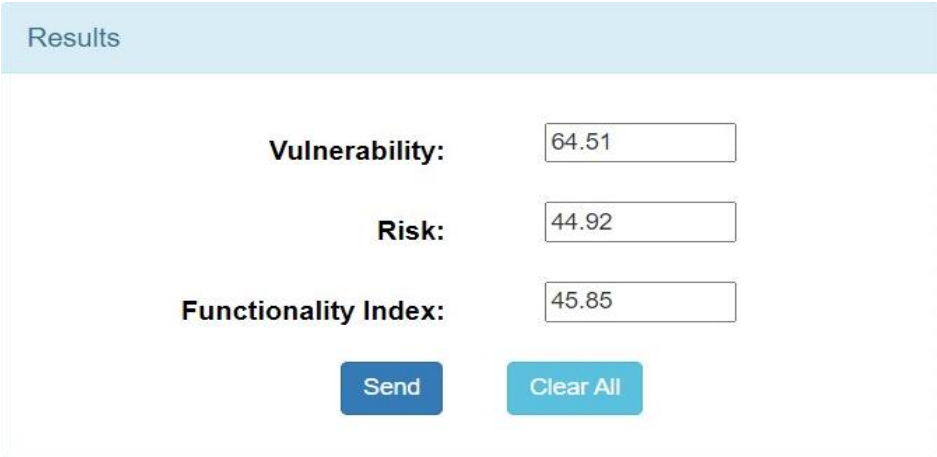
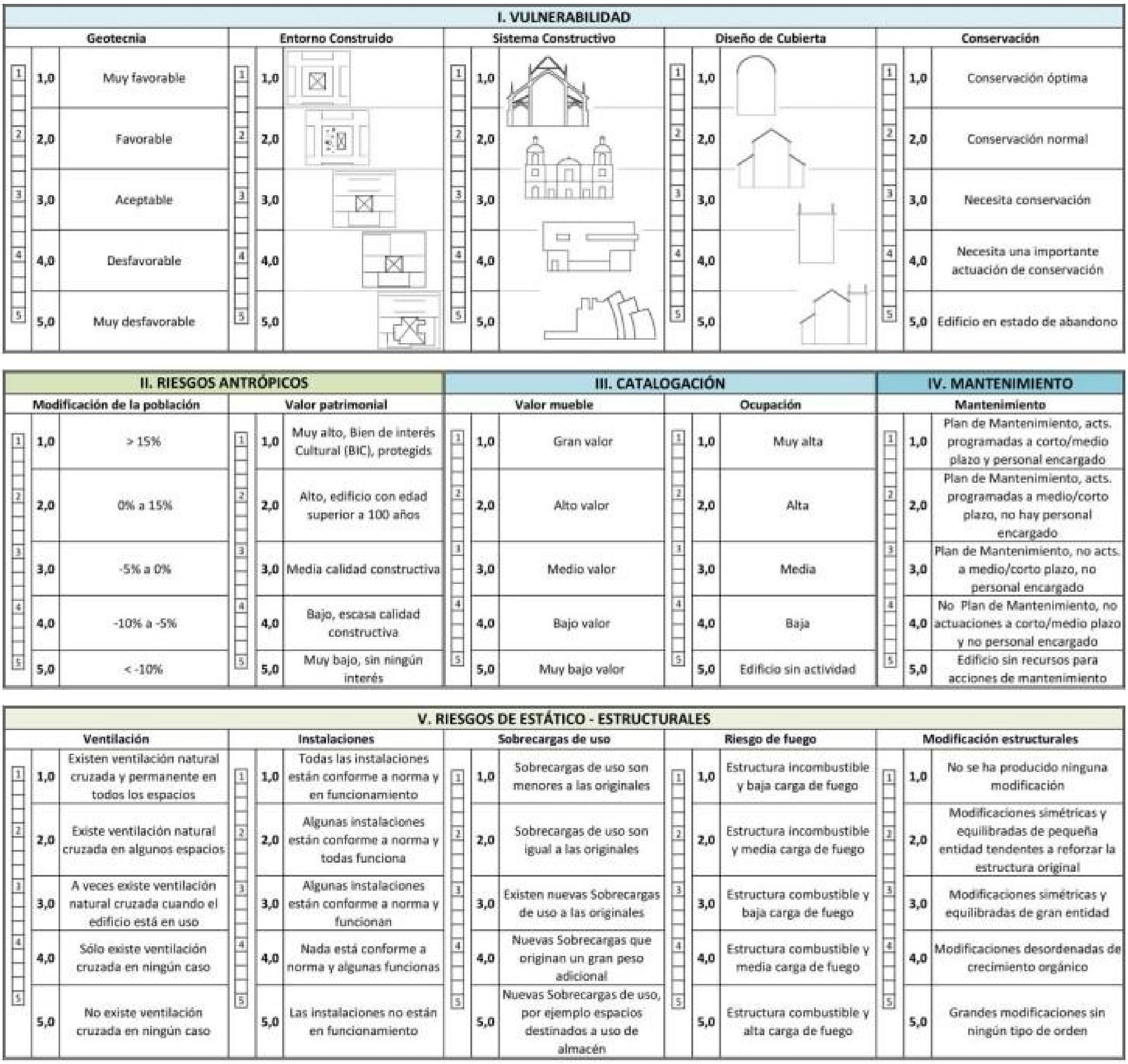


Figure 7. The Main Tool Consists of 14 Manual Input Variables (in black) and 5 Automatic Property Geolocation Variables (in grey), and the Resulting Values (vulnerability, hazard and functionality index)



I. VULNERABILIDAD									
Geotecnia		Entorno Construido		Sistema Constructivo		Diseño de Cubierta		Conservación	
1,0	Muy favorable	1,0		1,0		1,0		1,0	Conservación óptima
2,0	Favorable	2,0		2,0		2,0		2,0	Conservación normal
3,0	Aceptable	3,0		3,0		3,0		3,0	Necesita conservación
4,0	Desfavorable	4,0		4,0		4,0		4,0	Necesita una importante actuación de conservación
5,0	Muy desfavorable	5,0		5,0		5,0		5,0	Edificio en estado de abandono

II. RIESGOS ANTRÓPICOS				III. CATALOGACIÓN				IV. MANTENIMIENTO	
Modificación de la población		Valor patrimonial		Valor mueble		Ocupación		Mantenimiento	
1,0	> 15%	1,0	Muy alto, Bien de interés Cultural (BIC), protegids	1,0	Gran valor	1,0	Muy alta	1,0	Plan de Mantenimiento, acts. programadas a corto/medio plazo y personal encargado
2,0	0% a 15%	2,0	Alto, edificio con edad superior a 100 años	2,0	Alto valor	2,0	Alta	2,0	Plan de Mantenimiento, acts. programadas a medio/corto plazo, no hay personal encargado
3,0	-5% a 0%	3,0	Media calidad constructiva	3,0	Medio valor	3,0	Media	3,0	Plan de Mantenimiento, no acts. a medio/corto plazo, no personal encargado
4,0	-10% a -5%	4,0	Bajo, escasa calidad constructiva	4,0	Bajo valor	4,0	Baja	4,0	No Plan de Mantenimiento, no actuaciones a corto/medio plazo y no personal encargado
5,0	< -10%	5,0	Muy bajo, sin ningún interés	5,0	Muy bajo valor	5,0	Edificio sin actividad	5,0	Edificio sin recursos para acciones de mantenimiento

V. RIESGOS DE ESTÁTICO - ESTRUCTURALES									
Ventilación		Instalaciones		Sobrecargas de uso		Riesgo de fuego		Modificación estructurales	
1,0	Existen ventilación natural cruzada y permanente en todos los espacios	1,0	Todas las instalaciones están conforme a norma y en funcionamiento	1,0	Sobrecargas de uso son menores a las originales	1,0	Estructura incombustible y baja carga de fuego	1,0	No se ha producido ninguna modificación
2,0	Existe ventilación natural cruzada en algunos espacios	2,0	Algunas instalaciones están conforme a norma y todas funciona	2,0	Sobrecargas de uso son igual a las originales	2,0	Estructura incombustible y media carga de fuego	2,0	Modificaciones simétricas y equilibradas de pequeña entidad tendentes a reforzar la estructura original
3,0	A veces existe ventilación natural cruzada cuando el edificio está en uso	3,0	Algunas instalaciones están conforme a norma y funcionan	3,0	Existen nuevas Sobrecargas de uso a las originales	3,0	Estructura combustible y baja carga de fuego	3,0	Modificaciones simétricas y equilibradas de gran entidad
4,0	Sólo existe ventilación cruzada en ningún caso	4,0	Nada está conforme a norma y algunas funcionas	4,0	Nuevas Sobrecargas que originan un gran peso adicional	4,0	Estructura combustible y media carga de fuego	4,0	Modificaciones desordenadas de crecimiento orgánico
5,0	No existe ventilación cruzada en ningún caso	5,0	Las instalaciones no están en funcionamiento	5,0	Nuevas Sobrecargas de uso, por ejemplo espacios destinados a uso de almacén	5,0	Estructura combustible y alta carga de fuego	5,0	Grandes modificaciones sin ningún tipo de orden

V. RIESGOS DE ESTÁTICO - ESTRUCTURALES														
		Ventilación			**Instalaciones**			**Sobrecargas de uso**			**Riesgo de fuego**			**Modificación estructurales**
1	1,0	Existen ventilación natural cruzada y permanente en todos los espacios	1	1,0	Todas las instalaciones están conforme a norma y en funcionamiento	1	1,0	Sobrecargas de uso son menores a las originales	1	1,0	Estructura incombustible y baja carga de fuego	1	1,0	No se ha producido ninguna modificación
2	2,0	Existe ventilación natural cruzada en algunos espacios	2	2,0	Algunas instalaciones están conforme a norma y todas funciona	2	2,0	Sobrecargas de uso son igual a las originales	2	2,0	Estructura incombustible y media carga de fuego	2	2,0	Modificaciones simétricas y equilibradas de pequeña entidad tendentes a reforzar la estructura original
3	3,0	A veces existe ventilación natural cruzada cuando el edificio está en uso	3	3,0	Algunas instalaciones están conforme a norma y funcionan	3	3,0	Existen nuevas Sobrecargas de uso a las originales	3	3,0	Estructura combustible y baja carga de fuego	3	3,0	Modificaciones simétricas y equilibradas de gran entidad
4	4,0	Sólo existe ventilación cruzada en ningún caso	4	4,0	Nada está conforme a norma y algunas funcionas	4	4,0	Nuevas Sobrecargas que originan un gran peso adicional	4	4,0	Estructura combustible y media carga de fuego	4	4,0	Modificaciones desordenadas de crecimiento orgánico
5	5,0	No existe ventilación cruzada en ningún caso	5	5,0	Las instalaciones no están en funcionamiento	5	5,0	Nuevas Sobrecargas de uso, por ejemplo espacios destinados a uso de almacén	5	5,0	Estructura combustible y alta carga de fuego	5	5,0	Grandes modificaciones sin ningún tipo de orden

VI. RIESGOS MEDIOAMBIENTALES											
		Precipitación media			**Erosión por lluvia**			**Estrés térmico**			**Heladas**
1	1,0	Riesgo muy bajo (< 600 mm)	1	1,0	Zonas de riesgo mínimo. (< 7)	1	1,0	Riesgo mínimo	1	1,0	Riesgo mínimo (< 1 día)
2	2,0	Riesgo bajo (600 mm - 750 mm)	2	2,0	Zonas de Riesgo bajo. (7 - 8)	2	2,0	Riesgo bajo	2	2,0	Riesgo bajo (1 día - 5 días)
3	3,0	Riesgo medio (750 mm – 1000 mm)	3	3,0	Zonas de Riesgo medio. (8 - 9)	3	3,0	Riesgo medio	3	3,0	Riesgo medio (5 días - 20 días)
4	4,0	Riesgo Alto (1000 mm - 1200 mm)	4	4,0	Zonas de Riesgo alto. (9 - 10)	4	4,0	Riesgo Alto	4	4,0	Riesgo Alto (20 días - 60 días)
5	5,0	Riesgo muy alto (> 1200 mm)	5	5,0	Zonas de Riesgo máximo. (> 10)	5	5,0	Riesgo Máximo	5	5,0	Riesgo máximo (> 60 días)

VII. RIESGOS NATURALES					
		Riesgo por sismo			**Riesgo de Inundación**
1	1,0	Zonas de riesgo mínimo. (< 0.04 g)	1	1,0	Zonas de riesgo mínimo. (No inundables).
2	2,0	Zonas de Riesgo bajo. (0.04 g - 0.08 g)	2	2,0	Zonas de Riesgo bajo. (Periodo de retorno 500 años)
3	3,0	Zonas de Riesgo medio. (0.08 g - 0.12 g)	3	3,0	Zonas de Riesgo medio. (Periodo de retorno 100 años)
4	4,0	Zonas de Riesgo alto. (0.12 g - 0.16 g)	4	4,0	Zonas de Riesgo alto. (Periodo de retorno 50 años)
5	5,0	Zonas de Riesgo máximo. (> 0.16 g)	5	5,0	Zonas de Riesgo máximo. (Periodo de retorno 10 años)

Observaciones:

Figure 8. Recommended Model Form for Manual Data Collection in Technical Inspections. It Includes the 14 Input Variables for Each Building to be Assessed

The interpretation of each value obtained in the 'Results' section is described below:

Vulnerability	Actions
Low Vulnerability (<35)	The building is in excellent condition.
Medium Vulnerability (75-35)	The building has certain pathologies and conditions that should be studied in depth.
High Vulnerability (>75)	The building is in a poor state of conservation.

Hazard	Actions
Low Hazard (<35)	Acceptable level of environmental hazards
Medium Hazard (75-35)	Medium level for external environmental hazards.
High Hazard (>75)	High level for external environmental hazards.

Functionality index	Actions
High functional life (>75)	Optimum conditions of functionality.
Medium functional life (75-35)	Periodic inspections are required to ensure an acceptable level of functionality by specialist technicians.
Low functional life (<35)	Unacceptable level of functionality.

Figure 9. Output Variables

CONCLUSIONS

This study proposed the application of fuzzy logic to assess tangible and intangible values in the functional condition of Arc de Berà in the location of Tarragona, Catalonia, north-east Spain, the functional degradation condition, vulnerability, and external Risk. Despite the fact that the buildings are under the protection by the Asset of Cultural Interest and Historical Heritage standard of Spain and UNESCO, the Temple of Arc de Berà, recently restored in 1998, presents a medium functionality state (Condition B: Building requires periodical inspections, in order to maintain the minimal acceptable functional conditions), for the abandoned of the building and located inside of the city in an urban area.

The fuzzy logic model proposed in this study can help in the systematization of maintenance interventions in terms of decision-making by stakeholders. The ART-RISK 3.0 tool could be very useful for stakeholders, as an important reference for the diagnosis, and sustainable preservation of Arches. This study is the first application of this model in Arc de Berà, which remarks on the variety of the method of analysis. This model has made it to protect tangible and intangible cultural heritage which was previously neglected for a long period of time as a heritage to be preserved and must be the digitalization of result.

One key domain in which information technology has had a substantial impact is data management. The advent of Geographic Information Systems (GIS) has enabled archaeologists to integrate spatial data, such as maps and satellite imagery, with archaeological information. This integration facilitates improved visualization and analysis of archaeological sites, enabling researchers to discern patterns and relationships that were previously challenging to discern (Psarros, Stamatopoulos, & Anagnostopoulos, 2022). Furthermore, 3D modelling has emerged as a valuable tool in archaeological excavations. By generating precise and intricate threedimensional models of archaeological sites and artefacts, researchers can preserve digital replicas and disseminate them to the public. This not only aids in documentation and visualization but also facilitates virtual exploration and analysis of archaeological sites (Haddad et al., 2021). The integration of information technology into archaeological excavations has substantially propelled the field forward. It has enabled researchers to gather and analyze data with greater efficiency, make novel discoveries, and communicate their findings to a wider audience, The study underscores the significance of a multidisciplinary approach when addressing damages to stony cultural heritage (Mahmoud, 2021). Stony cultural heritage is susceptible to various forms of degradation, encompassing physical, chemical, and biological processes. Assessing and mitigating these damages necessitates expertise from multiple disciplines (Sanfilippo & Aquilia, 2018). In the case of Arch De Bera, a comprehensive assessment of the damage was conducted utilizing diverse scientific techniques. Material analysis techniques facilitated the identification of stone composition and comprehension of its mechanisms of deterioration. Imaging techniques provided intricate details regarding surface conditions and the presence of microorganisms. Based on the diagnostic findings, an appropriate treatment strategy was developed. This strategy encompassed cleaning, consolidation, and protection measures aimed at stabilizing the damaged elements and forestalling further deterioration. Importantly, these measures needed to be compatible with the original materials and respectful of the cultural significance of the site. The research (Silva, de Brito, & Gaspar, 2016; Prieto et al., 2019; Prieto et al., 2017) discusses the importance of linking the results of these articles with a Geoinformation System (GIS) to provide information about the conditions of the Monument or archaeological site and deterioration to determine priorities for intervention. This is consistent with the results of the current study and helps in future studies.

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