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VULNERABILITY ASSESSMENT TOOLS: FORECASTING AND ARTIFICIAL INTELLIGENCE

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Abstract *Vulnerability assessment is a very useful tool to identify, evaluate and prioritize the restoration of cultural heritage and the budgets of the monuments from a city or inside a region and to forecast the preventive conservation policies.*

The degradation of monuments could be due to the effects caused by structural damages, weathering affection, pollution agents, anthropogenic factors,… The conservation degree of each monument is the vulnerability, and its index is an indirect function of the level of deterioration. RIVUPH and ART-RISK are Spanish projects based on the analysis of environmental risk in historical cities and models to assess vulnerability. With this purpose risk and hazard maps of different towns are being built with GIS (geographic information system) software.

Each hazard has a given frequency and intensity in the historical cities according to their environmental conditions, these conditions change and depend on the location and the vulnerability of the monuments, for this reason GIS software and vulnerability models need to be developed in order to make decisions in historical cities.

The vulnerability analysis of three churches from Seville (Spain), have been studied to assess the monuments conservation degree. There are different approaches based on the variable studied (earthquakes, floods, fires,…), but it is necessary new methodologies that allow comparing and overlapping different scenarios. The monuments have been studied by a Delphi analysis and an artificial intelligence tool based on risk and vulnerability, these methodologies allow deciding the necessity of rehabilitation or preventive conservation.

1. INTRODUCTION

The diagnosis and preservation of cultural heritage, is a multidisciplinary scientific field that is based on knowing the symptoms and diseases of artworks or monuments to design the appropriate intervention and maintenance projects. Moreover, preventive conservation studies threats (hazards) against current degradation degree (vulnerability) to minimize risks [1], where vulnerability has near the same weight of the sum of hazards according to expert opinions [2].

Risk and vulnerability are defined by the European Council several times: 1) the recommendation on architectural heritage protection against natural disasters, adopted in 1993 [3], 2), the recommendation on cultural heritage protection against unlawful acts, adopted in 1996 [4], 3) the Recommendation for the continued conservation of cultural heritage against physical deterioration due to pollution, adopted in 1998 [5]. Nevertheless, disasters such as earthquakes, floods, fires, etc., have a high impact on the conservation of cultural heritage sites, monuments and art-works, moreover, the slow degradation of building materials is also caused by common environmental conditions, such as pollution, wind erosion, moisture, etc. In this regard, two separated risk strategies are usually employed: the first is a continuous action in response to the ravages of time and the second is associated with isolated events, for this reason, new multi-scenario approaches that take into account both kinds of agents are needed.

The knowledge of risks and hazards based on the experience and the archive of past and ancient episodes or disasters is part of risk management, which employs this information to decide the best strategies for preventive conservation [6]. Approaches to reduce risks in cultural heritage are a difficult and wide issue, as these studies can includes the analysis of hazards in a country [7] or a picture in a museum [8]. Each monument has a defined location with multi-scenario risks where the combination of threats and their importance must be studied [2].

The multi-scenarios analysis was initially studied in collections, archives and museums [9-12]. Opposite, whole monuments or cities are rarely studied under a risk methodology and their analyses are usually based on the assessment of mono-sceneries main risks [13-14]. Nevertheless, new approaches are currently being developed to analyse risks for monuments or archaeological sites [2, 15-16], with a huge bulk of data and scenarios, that implies the necessity to simplify models for decision-makers.

In Spain, the budget for restoration is decided in regions, and the town or city are the urban unit where territorial policies could be applied. For these reason, RIVUPH and ART-Risk methodologies are new approaches based on multidisciplinary analysis of environmental risk in historical cities in order to develop town global conservation strategies that can minimize the deterioration of monuments and reduce the cost of isolated interventions against hazards with urban plans.

The aim of these applied researches is to contribute to the preservation of cultural heritage, allowing the local and regional bodies to make decision of conservation based on scientific criteria. Imagine that you have ten monuments in a city and budget for conserving only two of them, a decision-making model would be necessary to know which of the monuments need immediate intervention, which monument need intervention in the long term and what preventive maintenance, so it would be possible to rationalize budgets. Our models compare different monuments, their vulnerability and risks in order to provide these decisions easier.

Our models aim to know the risks in a multi-stage system and evaluate them in terms of the vulnerability of the monument (as degree of health or disease), or functionality (as life). The tools are based on DELPHI expert panels and artificial intelligence to analyze the comparative diagnosis of a set of monuments with constructive similarities, compare their vulnerability, evaluate the environment, and allow decisions facing investment and budgets for intervention and preventive conservation.

In this paper, we present two models: Art-Risk-1, based on Delphy methodology, that allow calculating Vulnerability Index and Expanded Vulnerability Index [1] and Art-Risk-2 Model based on Fuzzy Logic that allows calculating Functionality Index, an overview of both methods and their results, and the comparison with other methodologies for diagnosis.

2. METHODOLOGY

These projects (RIVUPH/ https://www.upo.es/tym/en_rivuph.html and Art-Risk/ https://www.upo.es/investiga/art-risk-en/index.html) initially were based on the methodology developed by Galán et al. [17] in Spain for the analysis of vulnerability and the model of territorial risk analysis of Pio Baldi [7] for Italy. Under these principles, expert opinion have allowed to developed new criteria based on the Delphi method (Art-Risk-1 Model) and artificial intelligence (Art-Risk-2 Model).

Delphi methodology (Art-Risk-1 Model) has been used to consider the hazards and vulnerability of the monuments of Seville [1, 18-19] in order to obtain risk map as an overlapping of hazards and vulnerability maps. Seven experts with experience in cultural heritage have analysed the effects of different damages on cultural heritage monuments (hazards) and vulnerability variables.

This procedure, applied to the vulnerability analysis, has allowed modify the Leopold´s matrix of double entrance according to the methodology for assessment of environmental impacts developed by Galán et al. [17].

The diagnosis constitutes the qualitative vulnerability matrix that allow visualize and identify the relationships found for the environmental conditions and the conservation degree of the historical centers. Experts must carry out the study of weathering forms on-site according to the glossary of ICOMOS [20] and the standard 1/88 [21].

The vulnerability index (VI%) and the expanded vulnerability index (VIe%) for each monument were determined by the frequency and weathering degree of the deterioration patterns [1]. Finally, the vulnerability index (VI% and VIe%) are classified by vulnerability degree using classes described by Galán et al. [17]. More than 100 monuments has been classified in Andalucia by vulnerabity index [22], meanwhile 30 Churches (13^{th}-18^{th} Century) of Seville City has been studied by expanded index [1].

In these cases, hazards are classified in three categories following ICR methodology [7] to develop multi-scenarios hazard maps. The methodology have been improved from archeological monuments to building, in different cities as Merida, Estepa and Carmona, to obtain a validated methodology that has been used to analyse different hazards maps of Seville, Ronda and Cadiz [23].

The second method, (Art-Risk-2 Model) has been developed for managing risk affecting the service life of heritage sites with homogeneous characteristics [24]. This new approach has been developed in compliance with the risk management regulations (EN 31010, ISO 31000) [25-27] and in the environment of inference systems based on the Xfuzzy3.0 fuzzy logic design tool [28]. Functionality index was developed by identifying a total of seventeen input parameters,(vulnerability, static-structural, atmospheric and anthropic risk factors), validated and ranked by 15 experts, and which are related to the output parameter of the expert system: the durability of buildings [29]. 50 Churches (13^{th}-20^{th} Century) of Seville Province has been studied according to Art-Risk 2 Model.

Fuzzy expert systems were structured in four stages: “fuzzification”, in which input values, subject to certain imprecision and subjectivity, are represented by fuzzy sets; knowledge base; “inference” stage, in which fuzzy rules are defined such as modus ponens propositional inference rules (IF “fuzzy proposal” AND “fuzzy proposal” THEN “fuzzy proposal”; and “defuzzification”), which is used to generate specific output values [30].

The FBSL system developed by Macias [24] is supported by 5 vulnerability variables and 12 hazards that define the risks involved in the degradation of building functionality. The functionality index (FBSL) provide an orderly classification of priority actions for the conservation as vulnerability indexes.

For this methodology, a technical expert carry out the analysis of the service life of the buildings by on-site studies, where must answer questions about: a) conservation of constructive system and facilities, b) conditions of roof design, preservation, load state modification, dead and live loads, ventilation, fire and occupancy, and c) heritage value and furniture value. These opinions added to the geological location, environmental Conditions, inner environment, rainfall, temperature and population growth allow calculating the functionality indexes.

Xfuzzy3.0 free software used for this model was developed by the Institute of Microelectronics at the University of Seville in an open environment using the common specification language XFL3 [28]. The new version Xfuzzy3.0 has been programmed in Java, so the software can be run on any platform, using Java-RuntimeEnvironment (JRE).

Both methodologies are being developing in accordance with internationally CIB- W080 (International Council for Research and Innovation in Building and Construction) is advancing in predicting the life of building materials and elements, with the scope to promote international cooperation in useful life prediction materials and building components, by identifying systematic methodologies related to the evaluation and estimation of the useful life [31-34].

We present in this paper the comparative study of 3 churches: San Lorenzo, San Román and San Andrés by both methods (Art-Risk-1 and Art-ris-2). **.**

3. RESULTS

During the projects, the vulnerability index (Art-Risk Model 1) have been studied in more than one hundred monuments in Seville, Cadiz, Ronda, Marchena, Osuna, Estepa, Carmona and Merida [2, 18, 22, 35-37] to develop and improve the cognitive diagram of relationships between scenarios and vulnerability index [1].

For instance, the vulnerability identification matrixes employed in Seville, Marchena, Osuna, Estepa and Carmona, are mainly due to the impacts associated to erosion (dampness, change of temperature and wind pressure), pollutants, interventions and vandalism. Meanwhile, some weathering forms in Seville, Carmona and Estepa highlight stability influence. For these cities with similar seismic zone, the highest values of risk are found in Estepa and Carmona, which are dominated by the hazards of landslides. The presence of clay minerals around the edge of the hill is the cause of this static-structural risk.

The traffic is an environmental hazard scenario that has to be taken into account. This hazard is enhanced by the calcareous stones employed in most of themonuments.

Finally, the detailed evaluation of urban plan in the city of Marchena [37], as a theoretical positive factor, evidence the lass of building that should have been protected [22]. For this reason, urban protection level and cultural heritage use was included in the expanded vulnerability index [1].

On the other hand, Art-Risk 2 was applied in 50 Churches of Seville province [24]. This model quantifies the functionality as fuzzy buildings service life (FBSL) index, estimating the variables that influence the functionality of buildings. The validation has been made by working in different scenarios with different experts and analyzing the fulfillment according ISO 31.000 [30].

San Lorenzo, San Román and San Andrés were studied by both methods and results are included in table 1.

Table 1. Example of table layout

	Service life by FBSL (years)	VI (%)	Vie(%)
San Lorenzo	42	16	16
San Román	38	13	11
San Andrés	35	27	23

According to the results, the three churches have a low vulnerability degree and San Andres Church with the highest vulnerability indexes (VIe: 23%) and the lowest functionality values (FBSL: 35 years) would be the first monument to take into account for intervention in spite of its low vulnerability degree.

Scenarios of both methods have been compared in table 2, with some of the methodologies used on building diagnosis in order to understand the difference.

Table 2. Scenarios of analysis for different diagnosis methods.

	Ley 38/1999 [38]	CTE [39]	Spanish Cathedral Plan [40]	Italian Risk Map [7]	Vulnerability Matrix [17]	Art-Risk-1	Art-Risk-2
Application							
New Buildings	X	X					
Isolated Monuments			X		X		
Monument-Coparison						X	X
Historical centers						X	
Risk Maps				X		X	
Variables							
Geological Location				X	X	X	X
Environmental Conditions			X	X	X	X	X
Inner environment				X	X	X	X
Rainfall				X	X	X	X
Temperature				X	X	X	X
Population growth				X		X	X
Roof Design	X					X	X
Constructive system	X	X	X			X	X
Preservation		X	X	X	X	X	X
Load state modification	X	X	X	X	X	X	X
Dead and live Loads	X	X	X	X	X	X	X
Ventilation						X	X
Facilities	X						X
Fire	X			X		X	X
Heritage value						X	X
Furniture Value			X			X	X
Occupancy					X	X	X
Noise protection	X						
Energy earn	X						
Economical value							
Construction date						X	
Type of building						X	X
Number of Variables	8	4	6	10	9	18	18
Percentage	36%	18%	27%	45%	41%	82%	82%

Art-Risk 1 and 2 Models employed 82% of the variables and scenarios studied and are complementary in several aspects as the first one studies building disease or health, meanwhile Art-Risk2 assess the functionality.

Technical Inspections of Buildings [38-39] are used in Spain in the study of vulnerability, which vary according to local or regional law, for these reasons they cannot be used to compare buildings. Technical Building Code in Spain (CTE) [39] establish basic conservation levels depending on the service. Anyway, these inspection only have into account a few scenarios or variables (36-18%).

Spanish Cathedral plan have similar values (27%) while Baldi and Galan [7, 17] take into account 41-45% of the scenarios. Our models with 82% of variables, take into account most of the scenarios with small differences, tough they must be improved with analysis of cost/benefits and energy evaluation to improve the sustainability.

Both methodologies are complementary, benefits and drawbacks of each model are summarized in table 3.

Actions in the three churches depend on the uncertainty of the methods [1]. For this reason, further studies are been carried out to evaluate the accuracy and the reproducibility of the methods.

Table 3. Pros and Cons of Art-Risk 1 & 2

Model	Pros	Cons
Art-Risk1 Delphi Method	General Information Fast and non-expensive methodology We could classify interventions and preventive conservation Priority for restoration Risk and vulnerability are separated	Sampling Problems of incorrect inferences We need experts for surveys, in-situ diagnosis and science monitoring Mathematical development
Art-Risk-2 Fuzzy Method	General Information Fast and non-expensive methodology We could classify interventions and preventive conservation Priority for restoration No sampling Possibility of time series	Problems of incorrect inferences We need experts for in-situ diagnosis Mathematical development Risk and vulnerability are mixed Functionality index are not real useful life time

4. CONCLUSIONS

These new procedures provide scientific criteria to develop policies for making decision to preserve historical centers. These methods allow comparing risk between different cities to analyze strategies for cultural heritage conservation in a region, or inside a city, to evaluate the hazards of different zones in order to plan interventions.

The vulnerability or functionality indexes combined with the risk assessment, while limited in accuracy, are coherent and allow comparison between diverse monuments. This enables public body to make decisions for preventive conservation and prioritize the restoration resources of a city or even a region.

Preventive conservation of monuments requires a joint vision of a multidisciplinary team of diagnosis, in which the opinion of different disciplines, such as chemistry, architecture, archeology, conservators, art history, geology, biology can be taken into account and predictive mathematics and computer science that allows analyzing the data.

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