A New Tool Based on Artificial Intelligence and GIS for Preventive Conservation of Heritage Buildings

D. Cagigas-Muñiz[1], J.M. Martín[2], A.J. Prieto[3], A. Romero[1], R. Ortiz[2]

J. M Macías-Bernal[4], P. Ortiz[2,*]

[1] Department of Computer Architecture and Technology, ETSI
University of Seville, Seville, Spain
[2]Department of Physical, Chemical and Natural Systems
Pablo de Olavide University, Seville, Spain
[3]Institute of Architecture and Urbanism, Austral University of Chile, Valdivia, Chile
[4]Department of Architectural Construction II, ETSI, University of Seville, Seville, Spain

Abstract. This paper describes a new predictive model for preventive conservation of buildings. It allows for multi-scenarios of several hazards, assessments of environmental risks, and the use level of buildings together with cultural values of monuments. This modeling approach is based on fuzzy logic and geographic information system available to organizations dedicated to the restoration and rehabilitation in Spain. This system has a transversal development that includes urban, architectural, cultural heritage value, and the analysis of environmental and socio-demographic situations around the monuments. This new tool allows for decision-making based on scientific criteria and minimizes risk losses of cultural assets.

Keywords: Hazard, vulnerability, preventive conservation, artificial intelligence, GIS, heritage building.

1. Introduction

A monument is more than just the construction itself [1]; it is a part of the local identity and a source of memory of historical events [2]. National governments and European institutions increasingly recognise the importance of the conservation of cultural assets. The service life prediction of the materials and components of the built heritage should achieve their maximum permanence in order to avoid possible failures of buildings and future extremely costly interventions [3]. Fuzzy logic, introduced by Zadeh in 1965 [4], has been successfully applied in the construction area and this kind of models is especially interesting when the problems modelled are subject to uncer-

[*]Corresponding author: mportcal@upo.es

tainties. In this sense, fuzzy models present some advantages: (i) ability to model naturally systems that other models find vague and difficult to describe, (ii) ability to tolerate accurate and inaccurate data, (iii) ability for incorporating input information based on human observations, and (iv) ability to include the expertise of professionals [5].

The Geographical Information System (GIS) is a tool widely used in hazard evaluations [6], in assessments of flood risks when integrated with satellite remote sensing systems [7], and in combination with chemical techniques to study hazards from pollutants [8]. This paper presents a new tool based on Artificial Intelligence (AI) and includes GIS for environmental variables (GIS maps) that can be easily supplied by stakeholders and focused on the preventive conservation of heritage buildings. These methodologies are able to deal with the uncertainty associated with the performance loss of heritage buildings.

2. Methodology

The Art-Risk 3 model is a tool for the preventive conservation of cultural heritage that is based on a quantitative method able to deal with the uncertainty associated with the building's degradation process. Art-Risk 3 was developed by Art-Risk project funded by Spanish National Ministry and European Union. This modeling system is supported by 21 input parameters, nine involving vulnerability [9], one related to the building's maintenance, five static-structural risk parameters [10], four environmental risk parameters, and two naturals risk parameters (Table 1). These variables are involved in the functionality degradation of heritage buildings, their external risks and their own vulnerabilities, and provide a sequenced classification of priority actions for the conservation of the homogeneous architectural heritage.

Several parameters of the model pertain to the location of buildings, such as AR1 (geological location), AR16 (average rainfall), AR17 (rain intensity), AR18 (thermal stress), and AR19 (freeze danger). The ArcGIS ArcMap software from ESRI was employed to build GIS Map, where each hazard was determined utilizing a relative scale based on five values (Table 1). The remaining parameters are introduced manually by stakeholders (professional expert, users, practitioners, etc.). A total of 17 professionals with expertise from Spain, Portugal and Chile worked on the design of the model.

In general terms, the fuzzy expert systems are 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. The core of a fuzzy system is the knowledge base comprised of two components: The database and the rule base. This step is the principal part of a fuzzy expert system that combines the facts derived from the fuzzification process with the rule base generated previously and carried out in the modelling process [10]. Finally, the defuzzification stage is used to obtain a (crisp) value representing the fuzzy information produced by the inference. Based on this output model it is possible to obtain a priority ranking of maintenance activities related to the functionality, risks, and vulnerabilities of a set of built heritage with homogeneous characteristics.

Table 1. Input variables of the Art-Risk 3 model.

ID	Variables	Categories	Quantitative valuation (very low/medium/very high)	Descriptive valuation of the input parameters
AR1	Geological location	Vulnerability	1.0/3.0/5.0	Very favourable/acceptable/very unfavourable ground conditions
AR2	Built context		1.0/3.0/5.0	Buildings without or between complex constructions around it.
AR3	Constructive system		1.0/3.0/5.0	Uniform or heterogeneous characteristics of constructive system.
AR9	Roof design		1.0/3.0/5.0	Fast/normal/complex and slow evacuation of water.
AR10	Conservation		1.0/3.0/5.0	Optimal/normal/neglected state of conservation
AR4	Population growth	Anthropic Vulnerability	1.0/3.0/5.0	Population growth greater than 15%/0%/less than 5%.
AR5	Heritage value		1.0/3.0/5.0	Great/average/low historical value
AR6	Furniture value		1.0/3.0/5.0	High/average/low furniture value
AR7	Occupancy		1.0/3.0/5.0	High/media/low activity in the building
AR8	Maintenance	Maintenance	1.0/3.0/5.0	Good/average/bad building's maintenance
AR11	Ventilation	Static-Structural risks	1.0/3.0/5.0	Natural cross-ventilation in all or only in some areas.
AR12	Facilities		1.0/3.0/5.0	All/some facilities are in use or they are not ready to be used.
AR13	Overloads		1.0/3.0/5.0	Live load below/equal/higher than the original level.
AR14	Risk of fire		1.0/3.0/5.0	Low/medium/high fire load in relation with combustible structure.
AR15	Structural modification		1.0/3.0/5.0	Apparently/symmetric and balanced/disorderly modification.
AR16	Average Rainfall	Environmental risks	1.0/3.0/5.0	< 600 mmm/600 mm < 1000 mm/ > 1000 mm
AR17	Raindrop impact (Torrenciality index)		1.0/3.0/5.0	< 7/8 < 9/> 10
AR18	Thermal stress (Thermal amplitude)		1.0/3.0/5.0	< 6/6<10/<10
AR19	Frozen damage (days below 0)		1.0/3.0/5.0	< 1 day/5 days < 20 days/> 60 days
AR20	Seismic risk (acceleration)	Natural risks	1.0/3.0/5.0	< 0.04 g/0.08 g < 0.12 g/>0.16 g
AR21	Flooding (return period)		1.0/3.0/5.0	Never/100 years/10 years

3. Requirements, Design, and System Architecture

The Art-Risk tool has three important design requirements. It must be usable, accessible, and multiplatform. The usability is important because it is intended to be managed by the end users and is therefore required to conform to ISO 9241-11 standard which defines usability as "the extent to which a product can be used by specific users to achieve specific goals with effectiveness, efficiency and satisfaction in a specific context of use" [11]. As such, a user group evaluates the usability of the tool by performing several tasks and measures whether these tasks can be completed or not (effectiveness) on time in an efficient manner. Satisfaction for each task is measured using the Single Ease Question (SEQ) questionnaire. There is also a final questionnaire to test the overall satisfaction level using the System Usability Scale (SUS) standard questionnaire.

Accessibility is also a mandatory requirement according to the EU Directive 2016/2102 of the European Parliament on the accessibility of the websites and mobile applications of public sector bodies [12]. In this case the TAW online service is used. TAW is a mature and online tool with technical reference Web Accessibility Guidelines (WCAG 2.0) of W3C. It allows checking the accessibility of a certain URL. It generates a summary report based on the analyzed page with information about the result of the review [13]. Art-Risk is based on the standard web technology as is described below. The multiplatform characteristic is very relevant in Art-Risk. The tool can be used not only in desktop computers, but also in mobile devices. This facilitates the fieldwork and it speeds up large building evaluations and comparisons. Therefore, the user interface (front-end) of the Art-Risk tool must be responsive. Bootstrap and HTML5 technology are used to implement the user interface part.

Art-Risk architecture can be divided into two parts: A user interface or front-end and an AI engine or back-end. The Xfuzzy 3.3 tool models the Art-Risk AI engine. Xfuzzy 3.3 has a final synthesis stage that is divided into tools generating several high-level languages descriptions for software or hardware implementations. Its aim is to generate a system representation that could be used externally [14]. Art-Risk uses C language description of Xfuzzy 3.3 to generate a CGI or program (back-end) that is invoked by the user interface (front-end).

On the home page of Art-Risk [15] there are available 2.0 and 3.0 versions of this tool. The 2.0 version is based on a previous AI model, whereas the 3.0 version is an ongoing prototype version that adds some automatic input variables based on GIS maps that can provide some characteristics related to building's thermal stress, rainfall, or geothechnics. Here the *automatic* means that the users need only insert the building coordinates and the system will provide values for those variables associated with the stored GIS maps.

4. Conclusions

The prototype method described in this paper aims at evaluating the functional degradation conditions of heritage constructions. This methodology considers the consequences of natural, environmental, static-structural, and intrinsic and anthropogenic vulnerability conditions on the functional service life of cultural heritage (given by risks, vulnerability, and functional service life indices - Art-Risk 3).

The Art-Risk 3 methodology should be very useful in the management and organization of preventive maintenance-oriented activities of buildings. This approach can provide some guidance regarding the risks, vulnerabilities, and performance of buildings that should be carefully analysed in order to minimize the degradation of cultural heritage and their risk of failure. The expert system of the model is able to simulate human reasoning to study relations between vulnerability and risk factors of buildings through a fuzzy sets theory. Moreover, the utility of this system can increase with the users' inputs and can be upgraded and improved.

The described GIS + fuzzy methodology can be applied to different cultural heritage buildings, and can be adjusted to diverse environments in Europe and elsewhere. The model should enable building owners, users, public administrations, and private companies to use this open-access software to manage better the conditions of buildings.

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