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Original article

Expert system for predicting buildings service life under ISO 31000 standard. Application in architectural heritage

Andrés José Prieto Ibáñez[a,*], Juan Manuel Macías Bernal[a], María José Chávez de Diego[b], Francisco Javier Alejandre Sánchez[a]

[a] *Department Architectural Construction II, University of Seville, Seville, Spain*
[b] *Department Applied Mathematics I, University of Seville, Seville, Spain*

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The expert system for predicting the service life of buildings, fuzzy buildings service life (FBSL), is a computer application that contributes to the preventive conservation of architectural heritage. It establishes the process for evaluating and analysing the vulnerability and the main risks for heritage buildings, managing durability and service life according to their functionality. This paper demonstrates, after a detailed study and analysis of the two main reference standards in the field of risk management, namely the international standard ISO 31000:2009 and the European standard EN 31010:2011, that the FBSL expert system has been developed in compliance with the specifications established in these standards. This research justifies the use of this method, based on a new expert system that predicts the future service life of homogeneous heritage sites worldwide. This model manages the risk affecting these buildings and also complies with the aforementioned standards. Finally, the practical application of the FBSL expert prediction system was carried out through the study of a specific architectural heritage site.

1. Introduction

The *service life of* a building is established as its "*bearing capacity*, namely the capacity of a building to guarantee, with the necessary degree of reliability, the stability of the overall building and the necessary resilience, for a certain period of time, referred to as period of service" [1]. The analysis of this concept is included in international standard ISO 15686:2014 [2].

The assessment of the conservation status of a building and its durability over time is related to the components that make up the building, and are sensitive to events that generate one or various consequences, *vulnerabilities*. Extrinsic actions are considered to be effects of uncertainty in the building or *risks* [3,4].

Vulnerabilities and risks have been analysed in different ways [5]. In any case, the main aim of this study was to assess conservation status in architecture [6] including interactions with nature [7,8], static-structural and anthropic factors [9].

Haagenrud [10] shows that different agents cause deterioration, generating direct and indirect consequences in terms of building maintenance and repair costs. The service life of buildings is an important element in the socioeconomic stability of contemporary societies, representing fifty per cent of the wealth of most European countries at the beginning of this century.

The gradual degradation of architectural heritage buildings over time full concerns among users and influences their needs and expectations, prompting a significant increase in research into the buildings service life [11,12].

Until now, different predictive models [13–15] have been used to forecast the durability of architectonical elements [16,17], together with intelligent systems for regulating and controlling their installations. Modelled fuzzy in research to diagnose pathologies in architectural heritage [18] and in studies related with structural swings in the event of seismic tremors [19]. Neural network systems for controlling ventilation and wind chill among other applications [20,21].

The literature contains partial studies of building construction system; Vieira et al. [18] applies a fuzzy model to calculate the physical life of materials.

In contrast, the fuzzy building service life (FBSL) is a universal model developed by Macías-Bernal et al. [9] that classifies the functionality of a group of buildings with homogeneous characteristics based on inputs as the result of a system output. This expert system is, in fact, the first to combine the concept of building vulnerability with the external risks to which the building is subject. This model

* Corresponding author. Tel.: +34 637 744 525.
E-mail addresses: andpriiba@alum.us.es (A.J. Prieto Ibáñez), jmmacias@us.es (J.M. Macías Bernal), mjchavez@us.es (M.J. Chávez de Diego), falejan@us.es (F.J. Alejandre Sánchez).

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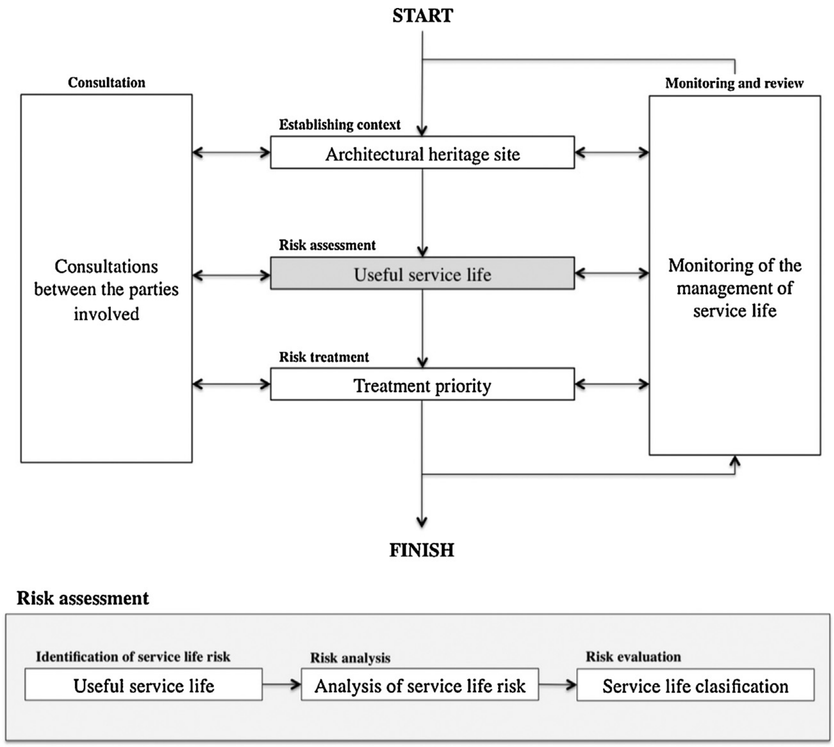

Fig. 1. Risk management process, ISO 31000.

is based on the fuzzy sets theory, developed in the 1960s–1970s by Zadeh [22] at Berkeley University and continued by Mamdani and Assilian [23] and Takagi and Sugeno [24]. The system is considered to be a new contribution in the field of expert systems based on fuzzy logic, capable of predicting the durability of buildings, thus contributing to the preventive conservation of architectural heritage. The aim of this study was to apply the FBSL under the international standard ISO 31000:2009 and the European standard EN 31010:2011, which regulate risk management and assessment, respectively. Field data on service life were gathered by assessing the preservation condition of 10 heritage buildings located in the Seville area, Spain.

2. Research objectives

The main aim of this article is to demonstrate that the new methodology for managing and assessing the risk affecting the service life of heritage sites with homogeneous characteristics – FBSL – conforms to international risk management standards. The new expert system for calculating the service life of buildings 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]. This environment is formed by tools that cover the different stages of the fuzzy system design process, from its initial description to its final implementation, through the common specification language XFL3 (a flexible and powerful language that enables the expression of very complex relationships between fuzzy variables using hierarchical rules, membership functions, fuzzification and defuzzification methods).

This model according to the functionality of homogeneous groups of heritage buildings was developed by identifying a total of seventeen input parameters, (vulnerability, static-structural, atmospheric and anthropic risk factors), validated and ranked by a group of experts, and which are related to the output parameter of the expert system: the durability of buildings [9].

3. General aspects of the ISO 31000 and EN 31010 standards

The ISO 31000, designed by the private organization International Organization for Standardization (ISO), is a powerful tool applicable to any organization engaging in the implementation and improvement of the risk management process. This process facilitates the taking of decisions related to uncertainty or the possibility of future events and their effects on objectives, and also provides policies, procedures and provisions for the integration of risk management at all levels of the organization. The EN 31010 governing risk management [27] is a supporting standard for the ISO 31000 [25]. The methodology of principles and guidelines is established for both standards (Fig. 1).

The standard has been developed as a common understanding and effective agreement for generating the necessary steps to adequately identify, manage and evaluate *risk*, the latter being defined as a "combination of consequences between events associated with a probability of future occurrence" ISO 31000 and ISO Guide 73:2009 [25,26].

The general provisions of this standard provide the guidelines to be followed by numerous industries and different types of systems. Similarly, the vast geographical areas in which the ISO 31000 and EN 31010 are applied [27] have fuelled the academic debate regarding their results and some of the main concepts they develop [29–32]. For example, Aven [3] argues that the standard could provide more effective definitions of some of the concepts covered in order to improve their definition by developing them in greater depth.

4. The FBSL and ISO 31000

This model [9] is developed in compliance with the ISO 31000 and EN 31010 standards (Figs. 1 and 2) and therefore complies with the specifications established in international legislation governing risk management, assessment and analysis. The management process is developed below.

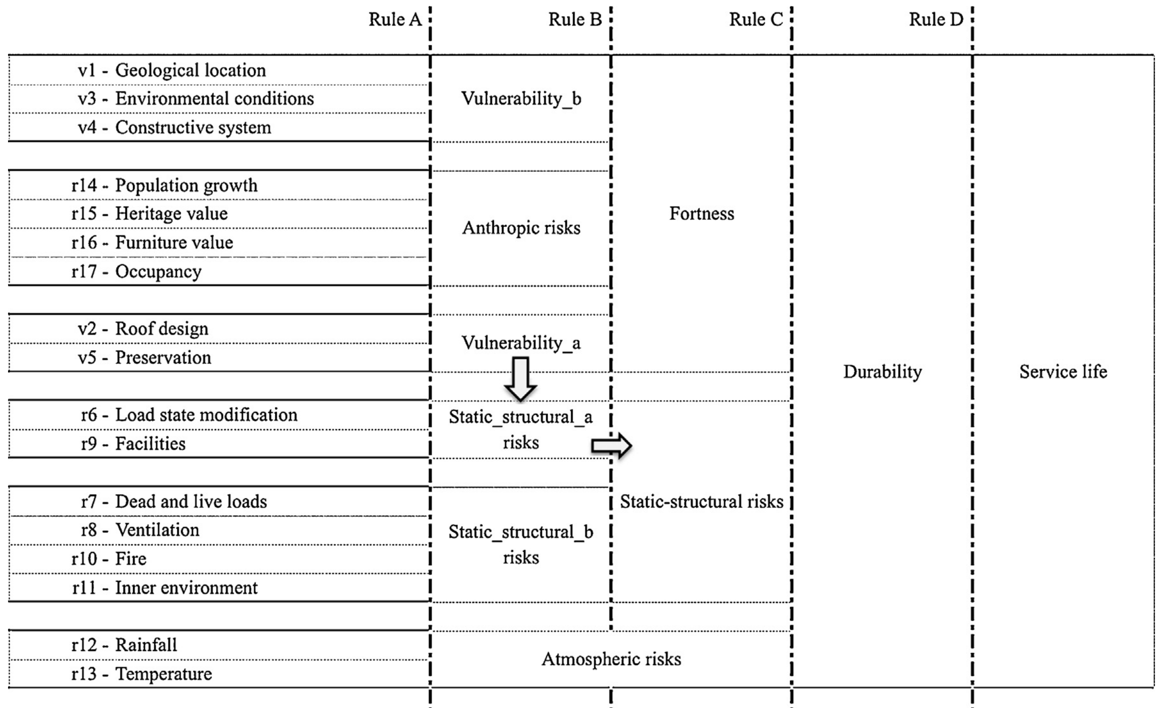

Fig. 2. Fuzzy buildings service life (FBSL) adjustment to ISO 31000.

4.1. *Consultation*

Sub-chapter 5.2 - ISO 31000 and 4.3.2 - EN 31010, in this first activity in the risk management process, effective communication and consultation are established between the involved parties: professionals with expertise in *preventive building maintenance* and public and private entities owning the buildings; this activity provides feedback during the management methodology (Fig. 2).

In fact, the FBSL communication plans are developed guaranteeing the interests of the entities participating in the process. The first phase (input) in our model requires multidisciplinary groups, responsible for identifying and analysing the main risks in the preventive conservation of architectural heritage. Thus, the risk of loss of service life of buildings is assessed, identified and addressed.

4.2. *Architectural heritage site*

In 5.3 - ISO 31000 and 4.3.3 - EN 31010, explain that when establishing the context (Fig. 1), the basic parameters for managing and assessing risk are defined, namely the objectives and scope of these parameters, the criteria for executing the rest of the process and the risk assessment programme. These criteria are set according to the nature and type of the consequences, the probability of future occurrence, the necessity and priority of treatment based on the service life of each building studied.

The framework of the FBSL expert prediction system is based on maintaining durability over time according to the functionality of homogeneous groups of buildings. Although the application of the model was limited to heritage sites with specific characteristics (religious buildings) located in municipalities in the province of Seville (southern Europe), making minor adjustments to certain parameters, the model would be able to predict the durability of other buildings sets, as output variable of the system, generating the ranking of priority treatment.

4.3. *Risk assessment*

In 5.4 - ISO 31000 and 4.3.4 - EN 31010, explain the assessment process corresponds to the core risk management activity developed in ISO 31000. The system is capable of analysing the objectives affected and identified in a structured manner, and the durability of buildings is analysed in terms of consequences and probabilities before deciding on a definitive action. Its purpose is to provide information and analysis-based evidence in order to be able to take decisions on the treatment of risks. This action plays a key role in the overall management process, consisting of the performance of a comprehensive risk analysis. The assessment is not treated as an isolated activity. Instead, it is integrated with the other activities of the management process (Fig. 1).

4.3.1. *Risk identification*

Sub-chapter 5.4.2 - ISO 31000 and 5.2 - EN 31010. The first risk assessment activity of FBSL, included in turn in the management process, performs the functions of identifying, analysing and assessing the service life of buildings. The application of this assessment process depends on the context in which this management is carried out, in this case to prevent the deterioration of architectural heritage. The activity also depends on the methods and techniques used. As a result, a multidisciplinary approach is required since the risks cover a wide range of causes and consequences (vulnerabilities), including foundations, structures, types of roofing or the geological location of the building in question [33].

Consequently, sufficient data must be used to take decisions relating to the needs for risk treatment and prioritization in the treatment of heritage buildings; hence, the need to identify events or situations that may affect the achievement of the objectives of the system, namely to extend the service life of heritage buildings.

4.3.2. *Risk analysis*

In 5.4.3 - ISO 31000 and 5.3 - EN 31010, explain that the core activity of the risk assessment process focuses on analysing service life risk in detail, through five intermediary activities (Fig. 2).

Table 1
Input factors.

Vulnerability	Static-structural risks	Atmospheric risks	Anthropic risks
v1 - Geological location	r6 - Load state modification	r12 - Rainfall	r14 - Population growth
v2 - Roof design	r7 - Dead and live loads	r13 - Temperature	r15 - Heritage value
v3 - Environmental conditions	r8 - Ventilation		r16 - Furniture value
v4 - Constructive system	r9 - Facilities		r17 - Occupancy
v5 - Preservation	r10 - Fire		
	r11 - Inner environment		

Thus, decisions are taken regarding the need to treat service life risk and the most appropriate methods for carrying this out, identifying the consequences and probabilities of future occurrence, in the event of an impairment in the service life of buildings, taking into account the effectiveness of all existing controls (Table 1). This is due to the fact that a building's relationship with its environment gives rise to a complex system of relationships between factors or variables. Thus, in situation in which available knowledge is imprecise or vague and data uncertainty is high, professionals with expertise in this field are consulted for their opinion, thus enabling "approximate reasoning" or "expert systems" models to be established [9].

4.3.2.1. Input factors. In 5.4.3 - ISO 31000 and 5.3.2 - EN 31010, define these parameters in FBSL, the following documents were reviewed: National Cathedral Plan; Law on Construction Planning; Rehabimed Method; Heritage Conservation Network; Technical Building Code; UNE 41805:2009 IN; ISO 15686 [2]. As a result of this activity, a total of seventeen vulnerability and risk factors were obtained (Table 1), which are determinant as FBSL system controls for defining the durability of buildings.

The level of effectiveness of these controls guarantees a certain level of accuracy, so it is important to record their effectiveness in order to assess the need to improve controls, or otherwise apply a different risk treatment approach for the preventive conservation of architectural heritage.

4.3.2.2. Vulnerability. In 5.4.3 - ISO 31000 and 5.3.3 - EN 31010, explain the consequences to be analysed and the stakeholders affected will have been decided when the context is established. It also addresses the nature and impact of such vulnerabilities because an event can lead to a range of impacts of different magnitudes and affect different objectives.

Consequence analysis controls in the FBSL model are considered to be inherent vulnerability factors of the building that treat the consequences, in this case related to the loss of buildings functionality, considering both their immediate actions and those appearing after a period of time (Table 1).

4.3.2.3. Fuzzification. In 5.4.3 - ISO 31000 and 5.3.4 - EN 31010, explain that refer to the likelihood analysis and probability estimation of risk, three tools are proposed: the use of historical data for identifying events or situations that have occurred in the past and thus be able to extrapolate the probability of their occurrence in the future; probability forecasting studies using predictive techniques such as fault tree analysis and event tree analysis; and, lastly, the use of expert opinion in systematic and structured processes (Fig. 2).

Assessing functionality in terms of the service life of a building and its relationship with the environment is undoubtedly a complex system of relationships between different factors, which usually require the opinion of experts in the field. In these types of situations in which different assessments of the input parameters are possible, traditional logic cannot be applied since no appropriate answer can be found.

The human brain differs from this strict philosophical-mathematical logic and broadens its reasoning combining as many other data and information as possible. For this reason, the fuzzy logic principles established by Zadeh were used [22]. This mathematical methodology represents imprecise knowledge where uncertainty is present, adding the application of expert experience to simulate human reasoning.

This system [9] was developed using probabilistic estimation in both the fuzzification stage, by translating linguistic labels that describe the assessment in which the input factors are present by membership functions, and the defuzzification stage in order to propose at the system output the estimated service life of the heritage buildings studied.

Additionally, when entering the input data, the opinion of a group of experts was taken into account to estimate the probability of future occurrence of the undesirable event, i.e. the impairment or reduction of the durability of buildings. Expert opinions provide all relevant and available information through the inclusion of historical data.

4.3.2.4. Hierarchical structure. In 5.4.3 - ISO 31000 and 5.3.5 - EN 31010, explain that the purpose is to ensure that resources will be focused on the most important risks, the taking care not to screen out low-risks, which occur frequently and have a significant cumulative impact.

Indeed, the hierarchical structure system (Fig. 3) makes certain factors prevail over others, thus conditioning the final result of the FBSL model. Conservation factors and roof design have greater weight than the other three vulnerability factors (v1, v3, v4). Anthropic factors are directly related to conservation status. Atmospheric risks have a direct impact on the durability of the structure [9].

The hierarchical structure is organized into four groups of inference rules (A, B, C, D), giving the functionality of buildings as the model output parameter [34], this structure allows a small number of variables to be studied at each level, thus achieving greater operability.

4.3.2.5. Fuzzy logic. In 5.4.3 - ISO 31000 and 5.3.6 - EN 31010, highlight the need to study variations or imprecisions in results, involving the determination of the size and significance of the magnitude of risk, as well as the degree of sensitivity of the system.

This activity is considered to have the greatest impact on the final result since adequate rules of inference or premises, based on fuzzy sets and established by experts and integrated into the hierarchical structure system, ensure the effectiveness of the FBSL for predicting the service life of buildings. This model provides an optimal response to this requirement of the standard, through the use of probability to estimate the service life of architectural sites with homogeneous characteristics.

4.3.3. Defuzzification

Sub-chapter 5.4.4 - ISO 31000 and 5.4 - EN 31010, establish assessment actions by comparing estimated risk levels to determine treatment priorities (Figs. 1 and 2).

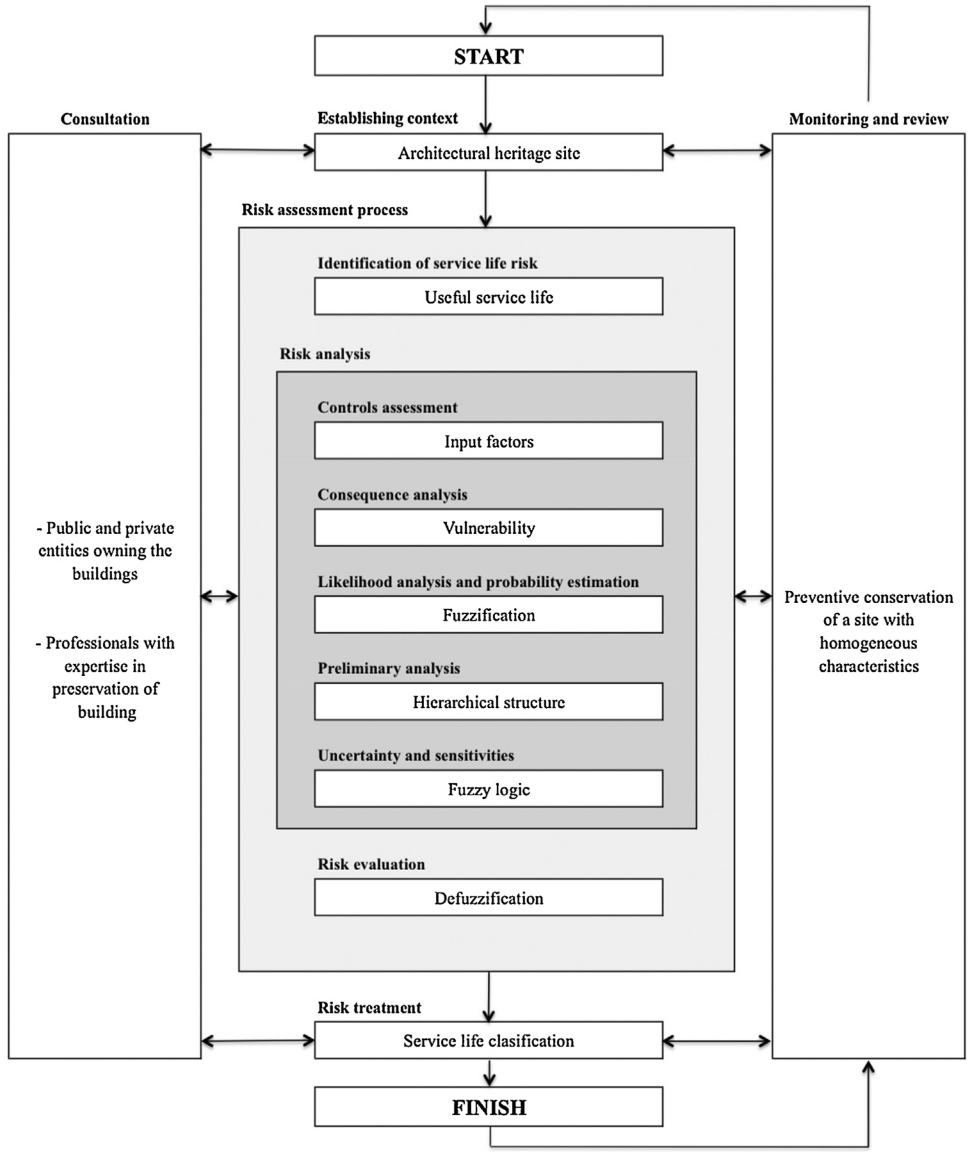

Fig. 3. Hierarchical structure, fuzzy buildings service life (FBSL) system.

The FBSL is used to obtain an orderly classification through the probabilistic estimation of the service life in years of homogeneous architectural sites. Based on the foregoing, three sections are developed based on the functional durability of buildings and the establishment of priority actions:

- an upper band; the level of risk is regarded as intolerable, priority treatment;
- a middle band or “grey” area; costs and benefits are taken into account and balanced;
- a lower band; the level of risk is regarded as negligible or so small that no risk treatment measures are needed.

4.4. Service life

In 5.5 - ISO 31000 and 4.3.5 - EN 31010, the methodology established by the ISO 31000 concluded with the monitoring and review of the entire process described previously, since for regular monitoring purposes.

The methodological process continued with treatment (Figs. 1 and 2), involving the selection and agreement between the probabilities that the risks related to the reduction in the service life of buildings, actually occur and generate effects resulting from incorrect management in building conservation and maintenance. Therefore, a critical reassessment of the new level of risk was performed in order to prevent the deterioration of buildings, determining their tolerance level, or further treatment if required.

4.5. Preventive conservation, site with homogeneous characteristics

In 5.6 - ISO 31000 and 4.3.6 - EN 31010 (Fig. 2), the FBSL is monitored by the continued reviews of the activities performed in the risk assessment and treatment processes in order to make comprehensive improvements to the management of the functionality the service life of heritage buildings. Efficient management, assessment and analysis of service life consists of studying this risk and its potential impact, providing enough information to the involved parties, contributing to the understanding of risk and helping to set priorities to prevent incidents in the preventive conservation of buildings.

ID	Architectural heritage site	ID	Architectural heritage site
1	 Parish church of San Pablo Situation: Aznalcázar	6	 Parish church of Nuestra Señora de la Antigua Situation: Almensilla
2	 Parish church of Nuestra Señora de las Nieves Situation: Benacazón	7	 Parish church of Nuestra Señora de la Granada Situation: Guillena
3	 Parish church of San Miguel Arcángel Situation: Castilleja del Campo	8	 Parish church of Nuestra Señora de la Nieves Situation: La Algaba
4	 Parish church of Santa María la Mayor Situation: Pilas	9	 Parish church of Santa María de Gracia Situation: Almadén de la Plata
5	 Parish church of Nuestra Señora de la Granada Situation: La Puebla del Río	10	 Parish church of Divino Salvador Situation: El Ronquillo

Fig. 4. Location of architectural heritage in southern Europe.

5. Methodology

Our model fulfils the requirements established in ISO 31000, as shown in the homogeneous set of buildings and the model implemented in Xfuzzy3.0 software described below.

5.1. *Architectural heritage site*

The scope of the study focused on 10 heritage buildings. They are located in an area of 14,036 km^2 in southern Europe (Fig. 4).

Table 2
Characteristics of buildings.

Main characteristics of these constructions
Three naves with small transept
Brick walls with some isolated mud walls
Stone doorway. Gothic apse with groin vaults, almost made of stone
Gable roof with wooden trusses and curved tiles (Arabic style)
Presence of crypts that are in use or hidden under the flooring
Bell tower with belfry and spire
Approximate dimensions of the building volume are: width 12 m, length 35 m and height 12 m. The floor surface area is around 420 m^2
Natural internal ventilation when the church is in use

The geographical area extends from the areas closest to the sea and the mouth of the Guadalquivir River in the south to altitudes of around 700 m in Sierra Norte of Seville. The buildings in the sample were built between the 15th–18th centuries (Fig. 4). Consequently, the parish churches have homogeneous constructive, cultural, political and regulatory features. However, the chronology and stylistic characteristics of Moorish buildings in the province of Seville display features that are unique of this kind of buildings [8,9]. All the buildings are located in the urban areas of the municipalities, and none of them is in a state of neglect or ruin. The most common formulations and specific features correspond to façade designs or the type of vaulting of the presbytery in several of the churches in the region studied (Table 2).

5.2. FBSL in Xfuzzy3.0 software

The FBSL model is a tool capable of generating estimates close to real values of the variables that influence the functionality of buildings. In general, 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 FBSL system is supported by the 17 vulnerabilities and risks involved in the degradation of the functionality of the buildings, providing an orderly classification of priority actions for the conservation of the homogeneous heritage site. This order of preference depends on the output value [9].

A technical expert performed the assessment and analysis of the service life of the buildings by studying the input parameters, i.e. the controls described in the ISO 31000 (Table 1).

The vulnerability and risk factors relating to the conservation of the homogeneous site were assessed as follows: parameter v1, with values ranging from 1.0 to 4.0; the other factors ranged from 1.0 to 8.0, where 1.0 was the best value and 8.0 the worst possible value.

The expert system studied here was implemented in Xfuzzy3.0 free software 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-Runtime-Environment (JRE). The tool has also been recently renovated to include new algorithms to generate graphical outputs for monitoring inference processes in 2D and 3D.

6. Results and discussion

Table 3 presents the controls assessments, which were then introduced into the Xfuzzy3.0 (Fig. 5). The final result of this process is a ranking of functionality values of each building in the homogeneous heritage site. This orderly classification of priority actions ranks in first place the buildings with lower service life scores, and therefore greater conservation needs (Table 3), and in last place orders the buildings with greater functional durability.

In light of the foregoing, it was shown that the model, through the 17 factors, is an indicator of trends in the future evolution of the functionality of buildings and provides a ranking of priority interventions and treatments of certain buildings with respect to others (Table 4).

Parish ID9, is analysed in detail below. The functionality of this building, according to the FBSL, was approximately 30 years (Tables 4 and 5 and Fig. 5), thus ranking in first place and therefore requiring priority treatment with respect to the rest of the heritage site studied.

In this case, it was observed that for an optimum score of 1.0 point for the v5-Conservation factor, the service life of the building achieved a maximum future durability of approximately 45.0 years. In contrast, when a value of 8.0 points (worst possible value) was applied to the FBSL model [9], the system output yielded a

Table 3
Assessment of the homogeneous heritage site through input factors.

ID - Architectural heritage site										
	1	2	3	4	5	6	7	8	9	10
Vulnerability										
v1	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	1.0
v2	2.5	2.0	2.0	6.0	2.0	2.0	2.0	4.0	3.0	5.0
v3	8.0	6.0	6.5	8.0	7.0	6.0	6.0	6.0	2.0	6.0
v4	4.0	4.0	5.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
v5	2.5	2.5	2.5	5.0	2.5	2.0	2.0	4.0	4.0	5.0
Static-structural risks										
r6	6.0	4.0	7.0	4.0	4.0	4.0	6.0	4.0	4.0	4.0
r7	4.0	6.0	6.0	5.0	4.0	6.0	4.0	4.0	4.0	4.0
r8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
r9	4.0	2.0	4.0	6.0	2.0	2.0	2.0	4.0	4.0	6.0
r10	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
r11	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Atmospheric risks										
r12	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0	5.5	5.5
r13	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	6.5	6.5
Anthropic risks										
r14	2.0	2.0	4.0	2.0	2.0	4.0	2.0	2.0	8.0	8.0
r15	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
r16	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
r17	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0

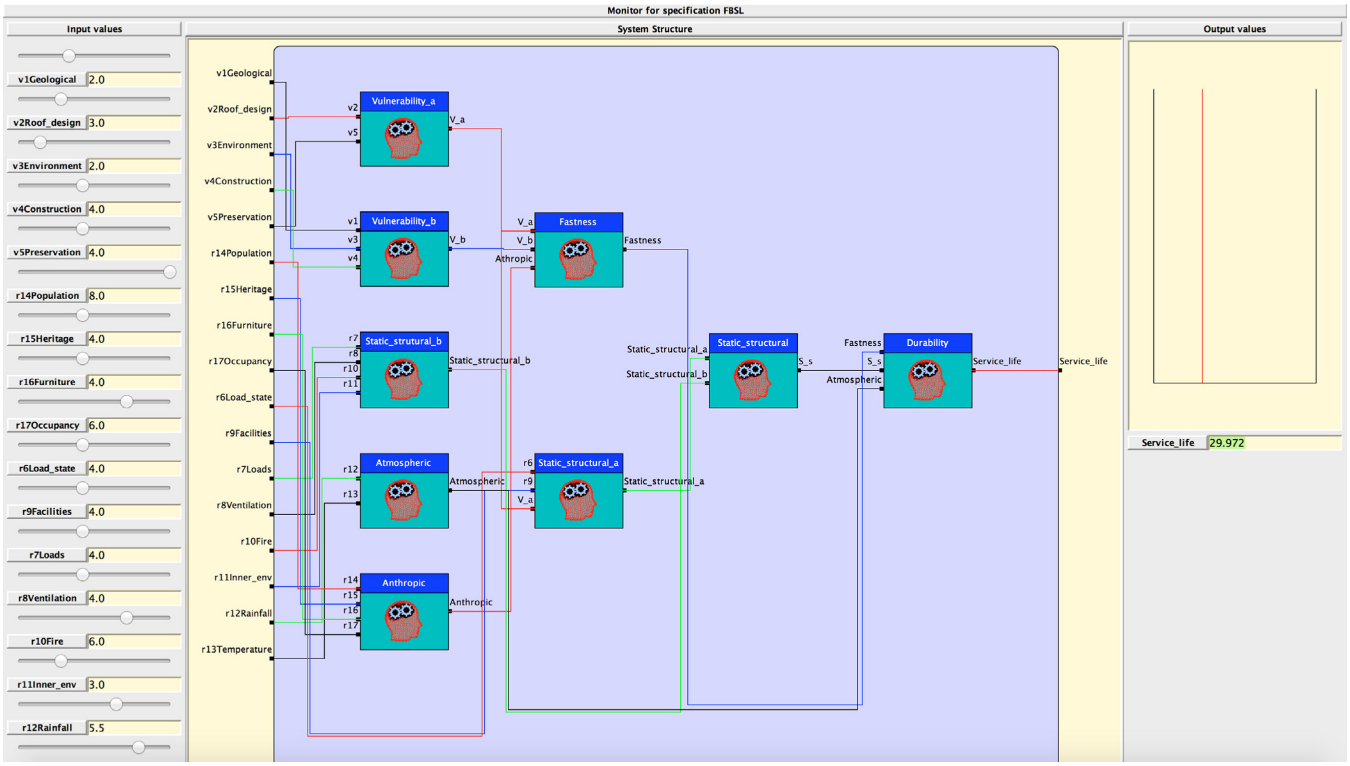

Fig. 5. Fuzzy buildings service life (FBSL). Estimated service life of parish ID9.

Table 4
Ranking of the architectural heritage site.

Classification	ID	Parish Church - Architectural heritage site	Situation	Service life by FBSL (years)
1°	9	Santa María de Gracia	Almadén de la Plata	30.0
2°	3	San Miguel Arcángel	Castilleja del Campo	31.0
3°	4	Santa María la Mayor	Pilas	33.5
4°	10	Divino Salvador	El Ronquillo	34.0
5°	8	Nuestra Señora de las Nieves	La Algaba	34.5
6°	1	San Pablo	Aznalcázar	36.0
7°	5	Nuestra Señora de la Granada	La Puebla del Río	38.5
8°	7	Nuestra Señora de la Granada	Guillena	39.0
9°	2	Nuestra Señora de las Nieves	Benacazón	39.5
10°	6	Nuestra Señora de la Antigua	Almensilla	45.5

FBSL: Fuzzy buildings service life.

service life value of 19.0 years, indicating that the factor v5 was the most influential, with a maximum-minimum in the estimation of durability for the ID9.

Table 4 shows the durability of a group of heritage buildings, the aim being to determine the relative position of certain buildings with respect to others in order to be able to determine actions to be taken based on the classification obtained after the application of the FBSL. The aim is to carry out preventive conservation actions on the group of heritage buildings studied since the service life of buildings can be extended if actions are taken more quickly to address the main factors responsible for their deterioration.

The result in years shown in Table 4 would be the consequence of not conducting any conservation work on the building in that period. Thus, it is estimated that at the end of that period, the building could be in a state of technical and economic ruin, making it much more costly to restore and subsequently use. The estimated time horizon is 100 years, as this is the longest period described in the bibliography for estimates in these types of buildings [10,17].

This finding was explained by the fact that the v5-Conservation factor was rated by experts contributing to the development of the model studied as the most influential in the functional durability of heritage buildings, thus reconfirming that it was the most determinant of all seventeen variables in the expert system.

Although all the inputs affected the final result of the model, the service life of the buildings (output), the v5-Conservation and v2-Type of roofing factors had the strongest influence in the expert prediction system [35], since it was also confirmed that the factor v2 had a significant impact on the fuzzy system output [34,36]. In contrast, the r11-Internal atmosphere factor was valued by the group of experts who validated the model as the variable with the smallest influence on the durability of the buildings. Similarly, it was found that the latter factor alone had a lesser impact on the model output.

These results show the potential of fuzzy modelling, despite the inherent uncertainty of the inputs, even for outliers. This model has been designed to generate a result for the service life of buildings in line with the valuation of input factors. Thus, the FBSL is able to record small fluctuations in the valuations of each input parameter, revealing positive or negative variations in the output of the system, i.e. the service life of buildings in years. Similarly, it was determined that in low-risk situations, durability translates into a high service life value.

Table 5
Valuation input variables, ID9.

	Valuation/(max.)	Justified valuation
Vulnerability		
v1 - Geological location	2.0/(4.0)	It is considered acceptable characteristics of the terrain Type pre-hercynian - cambricio - georgiense (microneis and calcosilicates)
v2 - Roof design	3.0/(8.0)	The building is restorated in 2002, it is accredited by a commemorative plaque It is considered a significant evacuation of water on deck
v3 - Environmental conditions	2.0/(8.0)	There are walls that separate from the other annexes to the perimeter buildings
v4 - Construction system	4.0/(8.0)	Different kinds of materials exists in the building construction systems
v5 - Preservation	4.0/(8.0)	An intermediate assessment of the conservation factor is performed, due to the last restoration in 2002
Static-structural risks		
r6 - Load state modification	4.0/(8.0)	The temple was repaired and further completed by the end of the seventeenth century, so are considered symmetrical and balanced strengthening small entity and changes the original structure
r7 - Dead and live loads	4.0/(8.0)	Imposed loads are maintained over time
r8 - Ventilation	4.0/(8.0)	It is available natural cross ventilation in some areas of the property
r9 - Facilities	4.0/(8.0)	The facilities are subject to the regulations in force and all are operational
r10 - Fire	6.0/(8.0)	2015 is considered a medium-low probability for combustion practically due to lack of internal lighting candles
r11 - Inner environment	3.0/(8.0)	The parish present good safety, cleanliness and hygiene of the spaces
Atmospheric risks		
r12 - Rainfall	5.5/(8.0)	Widely January, February, March, October, November and December are the highest amount of rainfall in the year, presenting a decrease in the remaining months
r13 - Temperature	6.5/(8.0)	High variation in temperature between days especially among night and day changes. It is due to the location in the Sierra Norte of Seville
Anthropic risks		
r14 - Population growth	8.0/(8.0)	Demographic analysis from 1591–2013 shows graphically the evolution of the population. Currently the population of Almaden de la Plata is in steady decline
r15 - Heritage	4.0/(8.0)	Although it has a high quality construction. The building is valued as a high patrimonial value, it is over 100 years of construction
r16 - Furniture value	4.0/(8.0)	Valoration lower-middle of the personal property located inside of building
r17 - Occupancy rate	6.0/(8.0)	It is considered a low occupancy in the building, due to the progressive decline in population in recent times

7. Conclusions

The FBSL complies with ISO 31000, and is a very easy way for users to comply with the requirements proposed in the standard, through risk management, assessment and analysis, contributing effectively and efficiently to the preventive conservation of architectural heritage.

This expert system was developed by identifying a total of seventeen input parameters, specifically vulnerability factors and static-structural, atmospheric and anthropic risk factors validated and ranked by a group of experts, closely related to the output parameter of the model: the durability of buildings. The system records minor fluctuations in the values of each input parameter, which are translated into positive or negative variances in the output values of the model.

The FBSL was applied to a homogeneous heritage site in southern Spain formed by a total of 10 buildings, showing that the model is an indicator of trends in the evolution of the functional durability of buildings in the future, resulting in a classification of priority actions to be performed in certain buildings with respect to others and favouring their subsequent preventive conservation in time.

This model can also be adapted to circumstances prevailing in other countries. Furthermore, the model can be improved by improving the sample, since more case studies can been incorporated. The expert system for predicting service life is able to learn based on experience acquired in previous cases. The main advantage of fuzzy modelling is its ability to deal with uncertainty, achieving better levels of performance and accuracy than those obtained with other kind of models. This model can be used to make an estimated classification of priority actions in heritage buildings, according to a set of different variables. Thus, FBSL can be used to manage the functionality of architectural heritage sets.

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