Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2021 Volume 27 Issue 6: 454–471
https://doi.org/10.3846/jcem.2021.15256

The special issue on the 100th anniversary of Lotfi A. Zadeh (1921–2017)
"Applications of Fuzzy Technology in Civil Engineering and Construction Management"

EXPERT PANEL ON IN-SITU VISUAL INSPECTIONS FOR MASONRY CHURCHES MAINTENANCE STAGE

Manuel CARPIO[1,2], Jesús ORTEGA[1], Andrés J. PRIETO[1*]

[1]*Department of Construction Engineering and Management, School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile*
[2]*UC Energy Research Center, Pontificia Universidad Católica de Chile, Santiago, Chile*

Received 5 January 2021; accepted 9 March 2021

Abstract. The incorporation of protocols in heritage building preservation is important for the definition of preventive conservation actions. Such integration is needed to avoid restoration actions and to promote preventive maintenance instead of corrective maintenance actions. This paper presents the application of an innovative digital management system using artificial intelligence that can quantify the suitability of a sample. This kind of application can support the maintenance management of buildings and minimise human error in data collection. The fuzzy system showed slight differences between the members of the expert panel during the in-situ visual inspection. These results indicate that, despite differences between various experts' evaluation of a building, the proposed digital method helps minimise the uncertainty in the results. The paper highlights input variables, which present high dispersion (load state modification, fire and occupancy), and input parameters, which present low dispersion (preservation, roof design and overloads). Fuzzy systems can adequately manage the uncertainties associated with different experts' assessment of sample that present constructive homogeneity. This study can give advantages to stakeholders during the inspection, diagnosis and evaluation stages in the improvement of mitigation policies focused on preventive maintenance programs dedicated to the resilience of heritage buildings, specifically churches emplaced in Chile.

Keywords: expert panel, fuzzy logic, preventive conservation, heritage buildings, churches, maintenance.

Introduction

The culture of a nation is influenced by buildings or structures that have historical significance. For centuries, buildings have had special meanings among people for economic or social reasons. In this context, churches have been permanent meeting places in Western culture. Communities have developed around them, and they remain in the memory of several generations as centers of development of their lives. For this reason, some churches have been declared heritage buildings. Their historical and cultural values are recognized, and these structures should be maintained and preserved to extend their service life. Ibrahim et al. (2008) noted that historical buildings are the most visible part of the history of a country and reflect a complexity of ideas and cultural values that is transmitted over time. Likewise, Khodeir et al. (2016) stated that heritage buildings are crucial for the human perception of culture and identity through time.

According to Augusti et al. (2001), a historical building is, by definition, a singular building characterized by its history; it is a combination of old and new elements which actively interact with each other. For these reasons, aside from being an important contribution to the overall costs throughout a building's life cycle, maintenance is becoming increasingly decisive for managing buildings (Flores-Colen et al., 2006). Hallberg (2009) noted that incorrectly planned and performed maintenance actions will comprise building performance over time. Therefore, methods, strategies and adequate planning for building preservation should be developed to preserve buildings' cultural heritage, avoid their degradation and maintain optimal functionality. Pintelon and Van Puyvelde (2006) explained that the criteria for the care of heritage buildings were defined based on the maintenance actions, maintenance policies and general support structure decisions by which they are planned and supported. In this sense, preventive maintenance covers all actions that are conducted at defined intervals to retain an item in a condition of use. These actions are performed through systematic inspection, de-

*Corresponding author. E-mail: *andres.prieto@ing.puc.cl*

Copyright © 2021 The Author(s). Published by Vilnius Gediminas Technical University

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

tection, replacement of worn items, adjustment, calibration and cleaning (Vega et al., 2016). From this approach, greater importance is given to tools that allow better management for the care of heritage buildings.

The United Nations Educational, Scientific and Cultural Organization [UNESCO] said that monumental buildings are than their construction itself (UNESCO, 2020). For UNESCO (2020), cultural heritage is any group of connected or separate buildings which hold outstanding universal value from a historical, artistic or scientific point of view because of their architecture, homogeneity or location. According to ISO 15686-4 (International Organization for Standardization [ISO], 2014), a building's "service life can be defined as the period of time after installation in which the buildings or their parts meet or exceed the minimum performance requirements". The preservation of architectural assets requires the development of methods, strategies and planning for the preservation of buildings. This is because, according to empirical studies, maintenance actions are influenced by the subjective perception of decision-makers. These actions usually do not depend on technical or economic factors. The incorrect implementation of necessary maintenance actions will generate a loss in the functionality of construction over time (Prieto et al., 2019).

Modelling the deterioration process of components and systems is essential for maintenance optimization models. In this sense, digital tools based on fuzzy logic system can be applied successfully in this area (Prieto et al., 2017). According to Silva et al. (2016), these models have the following main advantages: (i) capacity to tolerate accurate and inaccurate data; (ii) capacity to model natural systems, which other models find vague and confusing to describe; (iii) capacity to be developed using the expertise of professionals; (iv) capacity to input information based on human observations.

Since the input information to maintenance optimization models is based on observations from professionals, minimizing human errors is vital. Scientific studies have analyzed the influence of human errors on decision-making (Shor & Raz, 1988). Failures in decision-making are due to incorrect knowledge of buildings' intervention at a high percentage. Decision-making in a complex and dynamic environment is highly dependent on the level of awareness of the situation (Endsley, 2000). In scientific fields, it is used by expert panels to validate subjective assumptions or opinions (Carpio et al., 2015).

In the case of Chile, previous studies show that buildings with a high level of protection in accordance with Chilean standards do not always exhibit a high degree of functionality. High levels of protection do not always correspond to adequate preservation strategies (Prieto et al., 2019). One of the leading causes of this discrepancy is the lack of substance on the part of the main interested agents, as observed in a study conducted in Valdivia, southern Chile (Prieto et al., 2020). A study performed in a study area partially covered by UNESCO protection in Valparaíso, which is in the central coastal zone of the country, showed that the state of conservation of protected properties is not optimal due to lack of maintenance. This has forced stakeholders to focus more on the maintenance of the structures. In this sense, the management of conservation costs is a crucial instrument in the strategic planning of buildings, since these costs can be reasonably controlled.

Given these problems, the main innovation of this research work lies in how to analyze the service life status of heritage churches in the city of Santiago de Chile. In this study, a fuzzy logic system has been used. The digital system is based on previous experience criteria concerning several variables related to intrinsic vulnerability of heritage buildings and external hazard affections (Macías-Bernal et al., 2014) and regarding previous applications in set of buildings with homogeneous constructive characteristics emplaced in different location of South Europe (Spain and Portugal) (Prieto Ibáñez et al., 2016; Prieto et al., 2018) and in South America (Chile) (Prieto et al., 2019). This study has been conducted through an artificial intelligence-based methodology applied by a specific panel of experts to set intervention priorities, support the maintenance management of the buildings and minimize human errors in data collection and uncertainty associated to decision-making process. These kinds of approaches also contribute to the life cycle assessment (LCA) during the occupancy and maintenance stages of heritage buildings located in South Chile.

1. Materials and methods

1.1. Location and constructive characterisation of heritage churches

The Santiago Metropolitan Region, Chile, where the capital – Santiago de Chile – is located, has a territorial extension of 15,043 km^2 (Figure 1). This region is the most populated area in the country, with around 7,120,000 inhabitants, according to the 2017 census. Santiago has a temperate continental Mediterranean climate (Köppen classification Csb) characterized by winter rains and prolonged dry seasons (Kottek et al., 2006). Temperatures vary throughout the year, going from an average of 20 °C in January (summertime) to 8 °C in June and July (wintertime). Rainfall with concentration of about 75–80% occurs during the austral winter months (June to August), late autumn and even in early spring. The annual average rainfall in the region is around 342 mm.

This work analyses case studies regarding the conservation status of 12 heritage churches in the city of Santiago de Chile. These heritage buildings are categorized under heritage building conservation (HBC) by the communal regulatory plan (CRP) and under the Ministry of Housing and Urbanism of Chile (MINVU in Spanish) (Ministerio de Vivienda y Urbanismo [MINVU], 2019). These buildings are mainly located in two communes: Santiago and Providencia. The emplacement of the sample is shown in Figure 2. The Chilean methodology for defining protection values to cultural heritage assets is the current DDU-

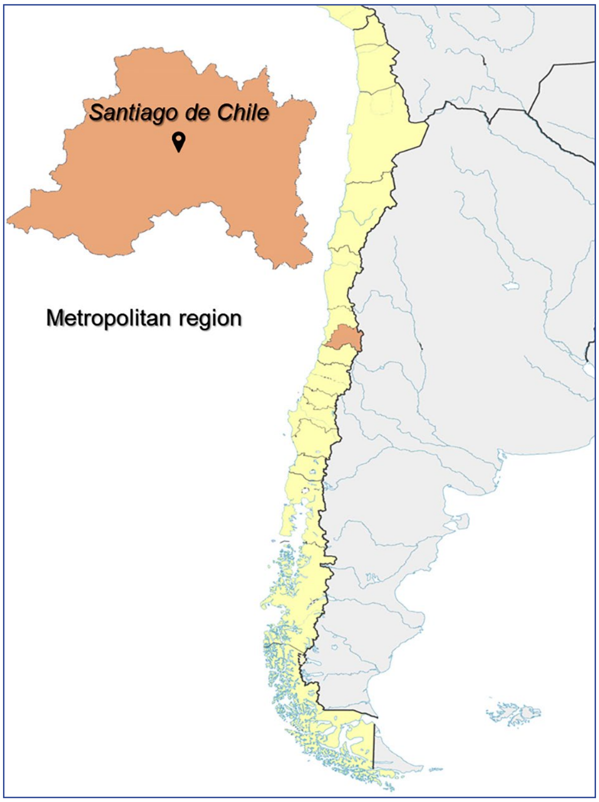

Figure 1. Location of Santiago de Chile, Santiago metropolitan region

Figure 2. Emplacement of the 12 heritage churches analysed (white) in the city of Santiago de Chile in the two communes (yellow)

400 standard (MINVU, 2019). For the definition of the Chilean protection standard value, the Community Regulatory Plan recommends analyzing some attributes: (i) urban value; (ii) architectural value; (iii) historical value; (iv) economic and (v) social value. The total value of the buildings varies between 0 and 24 points. In this sense, buildings with lower than 9 points do not present cultural heritage features that justify their protection as historic preservation properties, and buildings with a final value between 10 and 24 points have enough heritage attributes to be recognized as historic preservation properties.

For the selection of the churches, first, we standardized a time gap from construction to the present. The time gap was established to be between approximately 100 and 160 years; this produced a sample of churches dating from the middle of the 19th century to the beginning of the 20th century. Information was gathered from the records of the MINVU and more precise sources, such as the CRP and local ordinance (LO). Furthermore, for sample consistency, the churches were categorized by materiality; eleven (11) were mainly masonry, and one (1) was reinforced concrete.

The churches come in four architectural styles: neo-Baroque, Renaissance, Neoclassical and neo-Romanesque. The predominant style was neo-Baroque, which is characterized by the fusion or assimilation of various architectural trends (Widyaevan & Rahardjo, 2019), which at that time was shaped by the inspiration of renowned European architects from Italy, France, Germany and other countries. These churches are characterized morphologically by central naves with gabled roofs and, in some cases, by imposing towers at the sides. Most of them have brick walls complemented with quadrangular, circular or octagonal pillars. Inside, one can observe plaster decorations, parquet and/or wood block floors, light effects generated by different stained-glass windows and other elements of interest.

In general, the uniformity of certain characteristics was taken into consideration, such as facades, structural type, cover design, architectonic style, location, predominant material and the historical valuation level given by the national standard DDU-240 to determine whether a building has sufficient attributes to be recognized as an HBC. Figure 3 shows the set of heritage churches under analysis, and Table 1 describes their characterization.

In Table 1, 67% of the churches were built between 1857 and 1900, and the 33% remaining between 1901 and 1925. Regarding materiality, masonry is the main material used (92% of the total sample); reinforced concrete is used for only 8%. The locations of the buildings are quite close; 92% are located in the commune of Santiago (downtown), and 8% are relatively close (Providence). In addition, 100% of the HBCs are of a religious and ceremonial nature. In terms of architectural style, 58.33% of them are Neo-Baroque; 33.33% Renaissance and Neoclassical styles; and 8.33% Neo-Romanesque styles.

1.2. In-situ visual inspection

Visual assessment is a fundamental factor in any methodology used to inspect in situ (Menezes et al., 2015; Riggio et al., 2014), allowing quick and easy inspection even in poorly accessible areas (Menezes et al., 2015). In-situ visual inspection enables the qualitative characterization of anomalies, evaluation of their eventual problems (e.g. detection of past or current moisture problems) (Kasal & Anthony, 2004), causes and assessment of in-service conditions and amendment of existing documentation (e.g. claims reports, design elements and inspection reports) (Flores-Colen et al., 2006). A comprehensive visual inspection should include documentation of the original (or historic) structural system (Riggio et al., 2014).

Figure 3. Twelve heritage churches Santiago de Chile analysed in this study

Table 1. Characterisation of the 12 parish churches analysed in Santiago de Chile

ID	Parish church	Location	Construction finished (year)	Predominant material	Architectural style	Valuation (DDU-400)
StgoCh01	Parroquia y convento de la preciosa sangre	Santiago (downtown), Compañía de Jesús 2226	1910	Masonry	Neo-baroque	13
StgoCh02	San Martín de Porres	Santiago (downtown), Esperanza 1405	1880	Masonry	Neo-baroque	13
StgoCh03	Corazón de María	Santiago (downtown), Zenteno 764	1879	Masonry	Renaissance and Neoclassic	≥10
StgoCh04	Los Sacramentinos	Santiago (downtown), Santa Isabel 1127	1912	Masonry and reinforced concrete	Neo-baroque	≥10
StgoCh05	Cristo Pobre	Santiago (downtown), Matucana 540	1903	Masonry	Neo-romanesque	≥10
StgoCh06	San Ignacio	Santiago (downtown), Alonso Ovalle 1490	1872	Masonry	Renaissance and Neoclassic	≥10
StgoCh07	San Antonio de Padua	Santiago (downtown), Catedral 2345	1861	Masonry	Renaissance and Neoclassic	15
StgoCh08	Iglesia de la Gratitud Nacional	Santiago (downtown), Bernardo O'Higgins 2387	1883	Masonry	Neo-baroque	≥10
StgoCh09	San Saturnino	Santiago (downtown), Santo Domingo 2772	1900	Masonry	Neo-baroque	≥10
StgoCh10	Inmaculada Concepción	Santiago (downtown), Av. Brasil 915	1900	Masonry	Neo-baroque	12
StgoCh11	Veracruz	Santiago (downtown), José Victorino Lastarria 124	1857	Masonry	Neo-baroque	≥10
StgoCh12	Divina Providencia	Providencia, Avenida Providencia 1619	1890	Masonry	Renaissance and Neoclassic	≥10

Notes: Location: The commune, street name, street number are presented; StgoCh: Santiago Church; DDU-240: Standard to define the historical valuation level. Between 0 and 9 It does not have heritage attributes that justify its protection as an HBC. Ten (10) or more points It has enough heritage attributes to be recognized as HBC.

Non-destructive assessment methodologies for buildings, such as in-situ visual inspection, are generally inexpensive and can be performed rapidly to obtain relevant information regarding the degradation process of buildings or their materials (Meola et al., 2005). Knowledge about a building is crucial for successful analysis and sampling. In this sense, conservation and restoration plans should focus on sampling–analysis schemes (Silva et al., 2016).

The subjectivity of in-situ visual inspection depends largely on the knowledge and experience of inspectors (Menezes et al., 2015). In this study, it was ensured that the experts had adequate training to accurately assess the variables of the study. The panel of experts is made up of 7 international professionals, all with experience in construction, architecture and engineering (AEC) sector, with the following characteristics: i) Profession: Architect (14%), Civil Engineer specializing in Construction (57%) and Building Engineer (29%); ii) Academic level: Bachelor (28%), Master (43%) and Doctor (29%); iii) Professional experience: between 1 and 5 years (43%), between 6 and 10 years (14%) and more than 10 years (43%); and iv) nationality: Chilean (57%), Venezuelan (14%) and Spanish (29%).

The 12 buildings selected as case studies were inspected by the expert panel, each of whom individually performed a visual inspection. This panel consisted of seven professional experts who have education and experience related to heritage buildings. The knowledge and experience of these experts were mainly related to civil works construction, architecture and heritage, consulting in structural calculation, construction project management, civil works restoration and construction sustainability. In addition, they had an average of five years of professional experience in international construction. The research methodology is summarized in Figure 4.

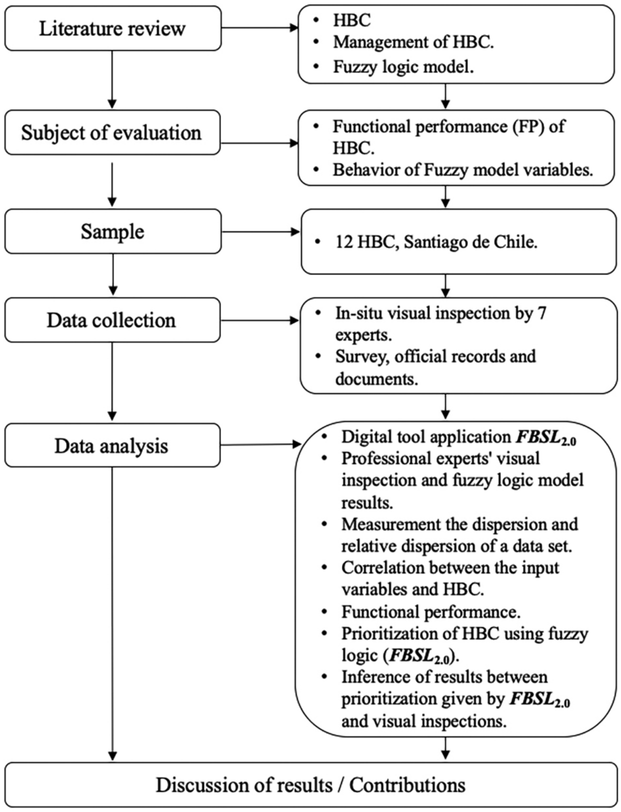

Figure 4. Research methodology

The fuzzy logic system ($FBSL_{2.0}$) presented in this research is based on previous experience criteria concerning several applications from an artificial intelligence system developed by the University of Seville (*FBSL*) (Macías-Bernal et al., 2014). Previous research focused on using this digital tool to validate the fuzzy model ($FBSL_{2.0}$) by applying it to new sets of buildings with homogeneous constructive characteristics in Spain (Prieto Ibáñez et al., 2016), Portugal (Prieto et al., 2018) and Chile (Prieto et al., 2019, 2020).

According to Figure 5, the fuzzy system comprises four main components or stages: (i) fuzzification process, (ii) fuzzy rule base, (iii) fuzzy inference engine and (iv) defuzzification process.

The fuzzification process transforms each crisp input data to degrees of membership by a lookup in several membership functions. In fuzzy logic, the idea is the allowance of partial of any situations to different subsets of

2. Fuzzy logic model

Fuzzy logic theory has been extensively applied as an instrument for decision-making processes in engineering, including the service life prediction of façade claddings (Silva et al., 2016). This methodology is particularly relevant when the modelled problem is subject to considerable uncertainty. In this sense, fuzzy logic, introduced by Zadeh in 1965, is able to model real-world phenomena (Zadeh, 1965). A general fuzzy logic system is shown in Figure 5.

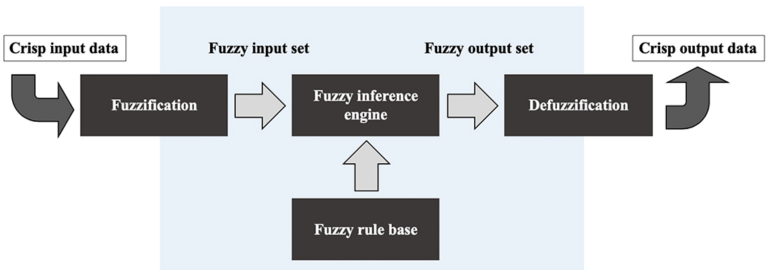

Figure 5. General fuzzy logic modelling process

a universal set instead of allocating these situations to a single set completely (Akkurt et al., 2004). Partial belonging to a set is explained mathematically by a membership function which assumes values between 0 and 1 inclusive. The membership functions of the set of input variables (5 vulnerabilities and 12 hazards) are Gaussian membership functions with the exception of the input variable v_1 (geological location), which used trapezoidal membership functions. In Tables 2 and 3, the 17 input variables of the computational model are particularly described concerning their qualitative and quantitative valuation.

The fuzzy rule base is the set of fuzzy inference rules established by the professional experts who participated in the model design stage. This set of rules is described using the IF–THEN format. In this fuzzy system, all uncertainties, including linear and nonlinear relationships, are defined in the descriptive fuzzy IF–THEN procedures (Jantzen, 2015). This model was defined using Mamdani fuzzy rules regarding input and output variables. The fuzzy rules were extracted from 15 constructors, engineers and architects' knowledge considering the experts' experience and judgment (Macías-Bernal et al., 2014). This model uses 354 fuzzy inference rules grouped into four levels of intermediate inference. The hierarchical structure of the fuzzy model ($FBSL_{2.0}$) is shown in Figure 6.

The fuzzy inference engine considers all the 354 fuzzy inference rules of the fuzzy rule base, which converts crisp input data to corresponding crisp outputs. The Mamdani inference mechanism is applied to compose the fuzzy propositions. This method works with the minimum operator as the implication function and with the maximum operator as the aggregation operator (Chai et al., 2009). Table 4 describes a set of 15 randomly selected fuzzy rules.

The defuzzification process transforms the fuzzy outputs from the inference engine to a number. This study used the centroid method, which is one of the most successful and commonly used defuzzification methods (Chandramohan et al., 2006). Concerning the applicability of this method, it is necessary to quantify all the input parameters (vulnerabilities and external risks) of the fuzzy

Table 2. Input variables related to vulnerability

Category	Ids	Input variables	Quantitative valuation (good/medium/bad)	Qualitative valuation
Vulnerability	v_1	Geological location	[1/2.5/4]	Very favourable/acceptable/very unfavourable ground conditions
	v_2	Roof design	[1/4.5/8]	Fast/normal/complex and slow evacuation of water
	v_3	Built context	–	Buildings without or between complex surrounding constructions.
	v_4	Constructive system	–	Uniform or heterogeneous characteristics of the construction system
	v_5	Preservation	–	Optimal/normal/neglected state of conservation

Table 3. Input variables related to static-structural, atmospheric and anthropic hazards

Categories	Ids	Input variables	Quantitative valuation (good/medium/bad)	Qualitative valuation
Static-Structural hazards	r_6	Load state modification	[1/4.5/8]	Slight modification/Symmetric and balanced modification/Disorderly modification
	r_7	Overloads	–	Live load below/equal to/higher than the original level
	r_8	Ventilation	–	Natural cross-ventilation in all/some areas / nowhere
	r_9	Facilities	–	All/some facilities are in use or are not ready to be used
	r_{10}	Fire	–	Low/medium/high fire load in relation to the combustible structure
	r_{11}	Inner environment	–	Maximum/medium/low level of health, cleanliness and hygiene of the building's spaces
Atmospheric hazards	r_{12}	Rainfall	[1/4.5/8]	Area with low/medium/maximum annual rainfall
	r_{13}	Temperature variation	–	Area with low/medium/maximum temperature differences
Anthropic hazards	r_{14}	Population growth	[1/4.5/8]	Population growth greater than 15%/around 0%/less than 5%
	r_{15}	Heritage value	–	Properties with great/normal/low historical value
	r_{16}	Furniture value	–	Social, cultural and liturgical appreciation (high/normal/low value)
	r_{17}	Occupancy	–	High/medium/low occupancy in the building

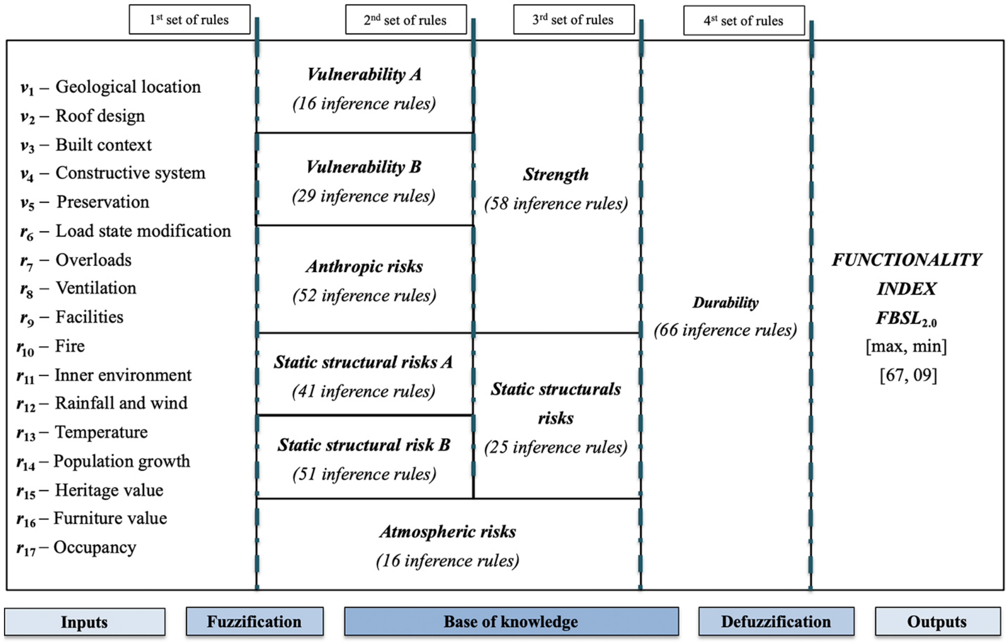

Figure 6. Hierarchical structure of the fuzzy inference system (*FBSL*2.0), including input, intermediate and output variables. Adaptation to the environmental context of central Chile

Table 4. Random selection of IF–THEN fuzzy inference rules

Rule	r_7	r_8	r_{10}	r_{11}	Static structural B risks
I	VL	VL	VL	L	VL
II	VL	VH	VL	VL	M
III	M	M	M	VH	H
IV	L	L	VL	L	L
V	M	H	M	M	M
VI	H	L	M	L	M
VII	VL	M	M	L	L
VIII	H	H	L	M	M
IX	VH	M	M	VH	H
X	VH	VH	VH	H	VH

Note: VL – very low; L – low; M – medium; H – high; VH – very high.

system. Prieto Ibáñez et al. (2016) established a functional degradation scale for heritage buildings (parish churches) based on the risk management standard ISO 31000:2018 (ISO, 2018); their scale has three levels of performance: (i) condition A – Upper level [67, 40], the level of risk is negligible, and the building presents an adequate functional level; (ii) condition B – Middle level [40, 20], the cost and benefits of preventive measures must be taken into account and balanced; (iii) condition C – Lower level [20, 09] the level of risk is intolerable and requires a high priority of intervention. The $FBSL_{2.0}$ fuzzy method allows building users, building owners and public administrations to manage the functional requirements of the deterioration of buildings (Marcinkowska, 2002). These classifications of functional conditions are able to realize an optimization of LCA of buildings in the occupancy and maintenance stage.

3. Results and discussion

3.1. In-situ visual inspection of the sample by the expert panel

Seven professional experts participated in the in-situ visual inspection of the selected heritage churches in Santiago de Chile. All the experts completed an inspection sheet, where the assessment of the 17 input variables is described. The purpose of this approach is to improve data collection through in-situ inspection to optimise the variables' valuation, which presents considerable dispersion. The in-situ visual inspection performed by the seven experts is described in Appendix, Tables A1–A12. This approach concerns the valuation difficulties encountered by the professional experts during their inspection and in relation to the 17 input variables of the fuzzy model ($FBSL_{2.0}$). In this sense, the input parameters, which presented high or low dispersion during the inspection stage, were analyzed. This analysis can help inspectors (engineers, architects and constructors) identify input variables easily, including those that are difficult to evaluate (Maliene et al., 2018).

Regarding the variables' valuation during the in-situ visual inspection, Table 5 summarizes the mean values of the experts' inspection valuation of the 12 heritage buildings. The input variables v_1 (geological location), r_{11} (inner environmental condition), r_{12} (precipitations), r_{13} (temperature) and r_{14} (population growth) present no changes in any building. This is due to their common valuation in all locations regarding the climatic and environmental conditions of their emplacement in Santiago de Chile.

The standard deviation (SD) of the inspection valuation of the experts per input variable in each case study is summarized in Table 6. SD is one of the most common measures of dispersion, and it indicates how dispersed the data are from the mean. A higher SD will correspond to a higher dispersion of data (Marôco, 2018). In this sense, the highest SD (±1.314) is identified for the input variable r_{16} (furniture value) for the case StgoCh04. This parameter (r_{16}) also presents the highest SD for StgoCh10 and StgoCh11 (±1.029 and ±1.018, respectively). The input variable r_7 (overloads) presents the lowest SD (±0.076) for StgoCh09. In terms of the minimum SD, v_5 (preservation) has an SD of ±0.157 for StgCh05. This is followed by ±0.189, which is found for r_6 (load state modification) for StgoCh04, and ±0.189, which is identified for r_7 (overloads) for the parish churches StgoCh01 and StgoCh03.

Table 7 summarizes the coefficient of variance (CoV) values of the experts' inspection valuation of the 12 heritage buildings. The CoV defines the relative dispersion of a dataset and corresponds to the ratio of the SD to the mean. The higher the CoV, the greater the level of dispersion around the mean (Marôco, 2018). This parameter is used to compare datasets belonging to different samples. Therefore, it enables one to have a measure of dispersion, which eliminates possible distortions in the media of two or more samples.

Table 5. Mean values concerning the valuation of the seven professional experts in each case.

Ids	StgoCh01	StgoCh02	StgoCh03	StgoCh04	StgoCh05	StgoCh06	StgoCh07	StgoCh08	StgoCh09	StgoCh10	StgoCh11	StgoCh12
v_1	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
v_2	2.2	2.0	3.1	1.9	3.0	2.6	2.5	2.9	2.1	2.4	2.2	2.2
v_3	2.7	2.9	3.3	2.7	3.3	2.9	2.2	2.9	2.6	2.4	2.5	2.2
v_4	1.8	1.6	2.1	1.7	1.9	1.8	1.5	2.0	1.8	1.2	1.4	1.9
v_5	1.7	2.7	2.0	3.3	2.7	2.0	1.9	1.7	1.7	2.3	2.1	1.4
r_6	1.3	1.3	1.4	1.1	1.1	1.3	1.1	1.2	1.3	1.2	1.1	1.2
r_7	2.1	2.2	2.1	1.9	1.9	1.9	1.9	1.9	2.0	1.9	1.9	1.9
r_8	2.0	2.8	2.5	2.3	2.2	1.8	2.9	2.0	2.0	2.3	2.6	1.5
r_9	1.5	2.4	1.9	3.0	2.5	1.8	1.7	1.4	1.3	1.8	1.8	1.2
r_{10}	1.7	1.9	1.6	2.0	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.2
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
r_{15}	1.7	1.9	1.9	1.4	1.7	1.7	1.6	1.4	1.6	1.6	1.7	1.7
r_{16}	1.8	2.1	2.1	2.6	2.1	2.1	2.4	2.1	2.1	2.4	1.9	2.0
r_{17}	1.1	2.1	1.7	2.7	2.0	1.2	1.9	1.5	1.7	2.3	1.9	1.7

Table 6. SD values concerning the valuation of the seven professional experts of each case

Ids	StgoCh01	StgoCh02	StgoCh03	StgoCh04	StgoCh05	StgoCh06	StgoCh07	StgoCh08	StgoCh09	StgoCh10	StgoCh11	StgoCh12
v_1	–	–	–	–	–	–	–	–	–	–	–	–
v_2	0.382	0.467	0.660	0.472	0.567	0.649	0.913	0.613	0.227	0.237	0.373	0.237
v_3	0.906	0.643	0.541	0.734	0.767	0.699	0.864	0.602	0.704	0.852	0.577	0.809
v_4	0.393	0.454	0.189	0.404	0.476	0.472	0.577	0.318	0.704	0.559	0.535	0.690
v_5	0.288	0.317	0.316	0.522	0.157	0.442	0.349	0.419	0.573	0.256	0.211	0.253
r_6	0.488	0.488	0.535	0.189	0.378	0.488	0.378	0.567	0.488	0.454	0.378	0.407
r_7	0.189	0.393	0.189	0.450	0.450	0.450	0.450	0.450	0.076	0.412	0.450	0.450
r_8	0.289	0.241	0.764	0.677	0.270	0.527	0.221	0.261	0.600	0.457	0.522	0.522
r_9	0.538	0.438	0.345	0.775	0.463	0.574	0.555	0.593	0.472	0.489	0.389	0.373
r_{10}	0.584	0.694	0.571	0.719	0.627	0.635	0.594	0.650	0.465	0.623	0.483	0.458
r_{11}	–	–	–	–	–	–	–	–	–	–	–	–
r_{12}	–	–	–	–	–	–	–	–	–	–	–	–
r_{13}	–	–	–	–	–	–	–	–	–	–	–	–
r_{14}	–	–	–	–	–	–	–	–	–	–	–	–
r_{15}	0.488	0.378	0.378	0.535	0.488	0.488	0.535	0.535	0.535	0.535	0.488	0.488
r_{16}	0.393	0.450	0.450	1.314	0.450	0.378	0.627	0.378	0.450	1.029	1.018	0.577
r_{17}	0.189	0.690	0.488	0.951	0.816	0.393	0.900	0.764	0.745	0.756	0.690	0.756

Three lowest CoVs for the input variables for the 12 case studies are gained in two vulnerability variables (v_5 [preservation] and v_2 [roof design]) and a risk variable (r_7 [overloads]). This result is relevant because these three input parameters (v_2, v_5 and r_7) have significant weights inside the fuzzy logic model ($FBSL_{2.0}$) (Prieto et al., 2017). By contrast, r_6 (load state modification), r_{10} (fire) and r_{17} (occupancy) have the highest CoV among all variables for the 12 heritage case studies. Considering these variables, only r_{17} (occupancy) has a relevant effect, i.e. important weight, in the model. Thus, the in-situ valuation of the input parameter r_{17} must be specifically analyzed in future research to minimize its dispersion.

Based on the preceding analysis (particularly the descriptions in Tables 2 and 3), Table 8 presents a correlation matrix between the vulnerability and hazard input variables and the heritage parish churches (input parameters in rows and heritage parish churches in columns).

Table 7. CoV values concerning the experts' inspection of the case studies

Ids	StgoCh01	StgoCh02	StgoCh03	StgoCh04	StgoCh05	StgoCh06	StgoCh07	StgoCh08	StgoCh09	StgoCh10	StgoCh11	StgoCh12
v_1	–		–	–	–	–	–	–	–	–	–	–
v_2	0.17	0.23	0.21	0.25	0.19	0.25	0.37	0.21	0.11	0.10	0.17	0.11
v_3	0.34	0.22	0.16	0.27	0.23	0.24	0.39	0.21	0.27	0.36	0.23	0.37
v_4	0.22	0.28	0.09	0.24	0.25	0.26	0.38	0.16	0.39	0.47	0.38	0.36
v_5	0.17	0.12	0.16	0.16	0.06	0.22	0.18	0.25	0.34	0.11	0.10	0.18
r_6	0.38	0.38	0.38	0.17	0.34	0.38	0.34	0.47	0.38	0.38	0.34	0.34
r_7	0.09	0.18	0.09	0.24	0.24	0.24	0.24	0.24	0.04	0.22	0.24	0.24
r_8	0.14	0.09	0.31	0.29	0.12	0.29	0.08	0.13	0.30	0.20	0.20	0.35
r_9	0.36	0.18	0.18	0.26	0.19	0.32	0.33	0.42	0.36	0.27	0.22	0.31
r_{10}	0.34	0.37	0.36	0.36	0.39	0.37	0.35	0.36	0.26	0.33	0.25	0.21
r_{11}	–		–	–	–	–	–	–	–	–	–	–
r_{12}	–		–	–	–	–	–	–	–	–	–	–
r_{13}	–		–	–	–	–	–	–	–	–	–	–
r_{14}	–		–	–	–	–	–	–	–	–	–	–
r_{15}	0.29	0.20	0.20	0.38	0.29	0.29	0.33	0.38	0.33	0.33	0.29	0.29
r_{16}	0.22	0.21	0.21	0.51	0.21	0.18	0.26	0.18	0.21	0.43	0.54	0.29
r_{17}	0.17	0.33	0.29	0.35	0.41	0.33	0.47	0.51	0.44	0.33	0.36	0.44

Note: '–' means no CoV.

Table 8. 'Case study – vulnerability and risk variables' correlation matrix regarding low, medium and high dispersion

Ids	StgCh01	StgCh02	StgCh03	StgCh04	StgCh05	StgCh06	StgCh07	StgCh08	StgCh09	StgCh10	StgCh11	StgCh12
v_1	–	–	–	–	–	–	–	–	–	–	–	–
v_2	L	M	M	M	L	M	M	M	L	L	L	L
v_3	M	M	L	M	M	M	M	M	M	M	M	M
v_4	M	M	L	M	M	M	M	L	M	H	M	M
v_5	L	L	L	L	L	M	L	M	M	L	L	L
r_6	M	M	M	L	M	M	M	M	M	M	M	M
r_7	L	L	L	M	M	M	M	M	L	M	M	M
r_8	L	L	M	M	L	M	L	L	M	M	M	M
r_9	M	L	L	M	L	M	M	M	M	M	M	M
r_{10}	M	M	M	M	M	M	M	M	M	M	M	M
r_{11}	–	–	–	–	–	–	–	–	–	–	–	–
r_{12}	–	–	–	–	–	–	–	–	–	–	–	–
r_{13}	–	–	–	–	–	–	–	–	–	–	–	–
r_{14}	–	–	–	–	–	–	–	–	–	–	–	–
r_{15}	M	M	M	M	M	M	M	M	M	M	M	M
r_{16}	M	M	M	H	M	L	M	L	M	H	H	M
r_{17}	L	M	M	M	H	M	H	H	H	M	M	H

Note: L – low dispersion; M – medium dispersion; H – high dispersion.

This matrix can be very useful for engineers, architects or constructors during the in-situ visual inspection of comparable case studies under environmental conditions similar to those in the present study. This correlation matrix enables the identification of the input variables that present low, medium or high dispersion for each case study examined.

This approach can help in the diagnosis process by giving indications for identifying the input parameters which pose considerable difficulties during in-situ visual inspections in similar contexts. Notably, visual analysis can achieve excellent results with minimal cost (Hughes & Callebaut, 2002).

In the intersection of each row and column, a correlation degree is defined considering the easiest or the most difficult valuation observed by each expert during the inspection. The degrees are as follows:

- L – low dispersion [< 0.19]; this variable of a case was easily evaluated by the professional experts.
- M – medium dispersion [0.20–0.39]; this variable presented a medium level of difficulty in the evaluation.
- H – [> 0.40] high dispersion; this variable was particularly difficult to evaluate.
- '–' – the variable's valuation was common among the case studies analysed.

3.2. Functional service life of the sample evaluated by the experts

This section analyses the functional service life of the sample considering three scenarios of the professional experts during the in-situ visual inspection: (i) mean scenario (Table 9), (ii) optimistic scenario (mean less SD; Table 10) and (iii) pessimistic scenario (mean plus SD; Table 11).

Considering the functional performance of the 12 heritage buildings, as indicated by the mean values of the expert panel, StgoCh04 presents the lowest functional service life value (55.68%) (condition A) (Table 9). Therefore, this heritage building requires first-order intervention. StgoCh01, which is ranked in the last position, has the highest functional service life (64.31%). In the mean situation, all the cases are ranked under functional condition A; the effects of vulnerabilities and external risks are small and do not require immediate intervention. This valuation is connected to the current in-situ visual inspection; a new in-situ visual inspection must be done if new scenarios occur.

In Table 10, the functional service life of the sample concerning low mean SD values of the experts' panel is described. These values correspond to an optimistic scenario of the experts during their inspection of the buildings. Again, StgoCh04 has the lowest functional service life (58.4%; condition A). In this optimistic scenario, the parish church StgoCh08 is ranked in the last position with the highest functional service life among the analyzed cases (65.4%; condition A) (Table 10).

Table 11 describes the functionality analysis of the sample contemplating the mean more SD values of the expert panel during the inspection stage. These valuations correspond to the pessimistic scenario. In this situation, the parish church StgoCh04 is also positioned in the first position and presents the lowest functionality index (51.6%; condition A) (Table 11). StgoCh01 has the highest functional performance (63.1%; condition A).

As per the analysis of the three scenarios, no case study changes its functional condition, either condition B (costs and benefits are taken into account and balanced) or condition C (vulnerabilities and risk of failure are intolerable and require immediate intervention). All case studies are ranged in Condition A (vulnerabilities and risk are negligible, and the building presents an adequate functional level). In this sense, this work contributes to the idea that, for the selected sample of buildings and the expert panel, the dispersion of data generated by the fuzzy logic model is low despite that different expert professionals can generate varying evaluations of the same building (case study). Therefore, the fuzzy model can adequately

Table 9. Functional service life of case studies considering the mean values of the experts' panel during in-situ visual inspection valuation

Id	v_1	v_2	v_3	v_4	v_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}	r_{17}	$FBSL_{2.0}$	Ranking	Functional condition
StgoCh04	3.9	1.9	2.7	1.7	3.3	1.1	1.9	2.3	3.0	2.0	2.0	3.0	3.0	2.5	1.4	2.6	2.7	55.68	1st	A
StgoCh05	3.9	3.0	3.3	1.9	2.7	1.1	1.9	2.2	2.5	1.6	2.0	3.0	3.0	2.5	1.7	2.1	2.0	58.42	2nd	A
StgoCh02	3.9	2.0	2.9	1.6	2.7	1.3	2.2	2.8	2.4	1.9	2.0	3.0	3.0	2.5	1.9	2.1	2.1	59.29	3rd	A
StgoCh10	3.9	2.4	2.4	1.2	2.3	1.2	1.9	2.3	1.8	1.9	2.0	3.0	3.0	2.5	1.6	2.4	2.3	59.91	4th	A
StgoCh07	3.9	2.5	2.2	1.5	1.9	1.1	1.9	2.9	1.7	1.7	2.0	3.0	3.0	2.5	1.6	2.4	1.9	61.17	5th	A
StgoCh09	3.9	2.1	2.6	1.8	1.7	1.3	2.0	2.0	1.3	1.8	2.0	3.0	3.0	2.5	1.6	2.1	1.7	61.67	6th	A
StgoCh03	3.9	3.1	3.3	2.1	2.0	1.4	2.1	2.5	1.9	1.6	2.0	3.0	3.0	2.5	1.9	2.1	1.7	62.06	7th	A
StgoCh11	3.9	2.2	2.5	1.4	2.1	1.1	1.9	2.6	1.8	1.9	2.0	3.0	3.0	2.5	1.7	1.9	1.9	62.22	8th	A
StgoCh08	3.9	2.9	2.9	2.0	1.7	1.2	1.9	2.0	1.4	1.8	2.0	3.0	3.0	2.5	1.4	2.1	1.5	62.86	9th	A
StgoCh06	3.9	2.6	2.9	1.8	2.0	1.3	1.9	1.8	1.8	1.7	2.0	3.0	3.0	2.5	1.7	2.1	1.2	63.37	10th	A
StgoCh12	3.9	2.2	2.2	1.9	1.4	1.2	1.9	1.5	1.2	2.2	2.0	3.0	3.0	2.5	1.7	2.0	1.7	63.43	11st	A
StgoCh01	3.9	2.2	2.7	1.8	1.7	1.3	2.1	2.0	1.5	1.7	2.0	3.0	3.0	2.5	1.7	1.8	1.1	64.31	12nd	A

manage the uncertainty processes associated with the assessment of different expert professionals of case studies that present constructive homogeneity (Zadeh, 1983). In the three examined scenarios (mean, optimistic and pessimistic), the same building (StgoCh04) is identified as the parish church with the highest intervention priority (Tables 9–11). These kinds of fuzzy logic applications are useful for developing integral preventive maintenance and conservation programs for heritage buildings (Rosina, 2018).

Figure 7 shows a comparative analysis between the three scenarios. Four heritage buildings (StgoCh04, StgoCh05, StgoCh02 and StgoCh10; 33.3% of the sample) are ranked the highest, presenting the lowest functional performance in the three scenarios. Thus, these case studies should be given first-order intervention (Figure 7). Moreover, StgoCh06 is classified in the same position (10th) in the three modelled situations. The 41.6% of the sample analyzed is classified in the same ranking position considering the three scenarios of the expert panel during the in-situ visual inspection of the cases.

Three cases studies (25% of the sample) are matched between only two scenarios (mean and pessimistic). StgoCh07 is ranked in the 5th position of intervention priority in both situations. StgoCh12 and StgoCh01 are ranked 11th and 12th, respectively (Figure 7). In the same way, only one case study (StgoCh03; 8.3%) is matched between the optimistic scenario and the mean scenario concerning the experts' valuation during the inspection stage. StgoCh01, StgoCh07 and StgoCh12, which account for 25% of the sample, are not matched in any of the three scenarios modelled.

Regarding this approach, different elements may be discussed: (i) The management of uncertainty in an expert panel is an important intrinsic issue in the application of fuzzy expert systems. Nevertheless, the proposed fuzzy logic model can manage the dispersion in an expert panel and produce coherent results in the functional valuation

Table 10. Functional service life of case studies considering mean less SD values of the experts' panel during in-situ visual inspection valuation – optimistic scenario

Id	v_1	v_2	v_3	v_4	v_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}	r_{17}	$FBSL_{2.0}$	Ranking	Functional condition
StgoCh04	3.9	1.4	2.0	1.3	2.7	1.0	1.5	1.6	2.2	1.3	2.0	3.0	3.0	2.5	1.0	1.3	1.8	58.4	1st	A
StgoCh05	3.9	2.4	2.5	1.4	2.5	1.0	1.5	1.9	2.0	1.0	2.0	3.0	3.0	2.5	1.2	1.6	1.2	61.4	2nd	A
StgoCh02	3.9	1.5	2.3	1.1	2.4	1.0	1.8	2.6	1.9	1.2	2.0	3.0	3.0	2.5	1.5	1.6	1.5	62.5	3rd	A
StgoCh10	3.9	2.1	1.5	1.0	2.0	1.0	1.5	1.8	1.4	1.3	2.0	3.0	3.0	2.5	1.0	1.3	1.5	62.5	4th	A
StgoCh11	3.9	1.9	1.9	1.0	1.9	1.0	1.5	2.1	1.4	1.4	2.0	3.0	3.0	2.5	1.2	1.0	1.2	63.4	5th	A
StgoCh12	3.9	2.0	1.4	1.2	1.1	1.0	1.5	1.0	1.0	1.7	2.0	3.0	3.0	2.5	1.2	1.4	1.0	63.7	6th	A
StgoCh03	3.9	2.5	2.8	1.9	1.7	1.0	1.9	1.7	1.6	1.1	2.0	3.0	3.0	2.5	1.5	1.6	1.2	64.0	7th	A
StgoCh09	3.9	1.9	1.8	1.1	1.1	1.0	2.0	1.4	1.0	1.3	2.0	3.0	3.0	2.5	1.0	1.6	1.0	65.0	8th	A
StgoCh01	3.9	1.9	1.8	1.4	1.4	1.0	1.9	1.7	1.0	1.1	2.0	3.0	3.0	2.5	1.2	1.4	1.0	65.1	9th	A
StgoCh06	3.9	1.9	2.2	1.4	1.6	1.0	1.5	1.3	1.3	1.1	2.0	3.0	3.0	2.5	1.2	1.8	1.0	65.1	10th	A
StgoCh07	3.9	1.6	1.4	1.0	1.6	1.0	1.5	2.7	1.1	1.1	2.0	3.0	3.0	2.5	1.0	1.7	1.0	65.3	11st	A
StgoCh08	3.9	2.3	2.3	1.7	1.3	1.0	1.5	1.7	1.0	1.2	2.0	3.0	3.0	2.5	1.0	1.8	1.0	65.4	12nd	A

Table 11. Functional service life of case studies considering the mean more SD values of the expert panel during in-situ visual inspection valuation (pessimistic scenario)

Id	v_1	v_2	v_3	v_4	v_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}	r_{17}	$FBSL_{2.0}$	Ranking	Functional condition
StgoCh04	3.9	2.3	3.5	2.1	3.8	1.3	2.4	3.0	3.8	2.7	2.0	3.0	3.0	2.5	2.0	4.0	3.7	51.6	1st	A
StgoCh05	3.9	3.6	4.0	2.3	2.8	1.5	2.4	2.4	2.9	2.3	2.0	3.0	3.0	2.5	2.2	2.5	2.8	55.5	2nd	A
StgoCh10	3.9	2.6	3.2	1.8	2.5	1.6	2.3	2.7	2.3	2.5	2.0	3.0	3.0	2.5	2.1	3.4	3.0	55.9	3rd	A
StgoCh02	3.9	2.5	3.5	2.0	3.0	1.8	2.6	3.1	2.8	2.6	2.0	3.0	3.0	2.5	2.2	2.5	2.8	56.7	4th	A
StgoCh07	3.9	3.4	3.1	2.1	2.3	1.5	2.4	3.2	2.2	2.3	2.0	3.0	3.0	2.5	2.1	3.0	2.8	56.9	5th	A
StgoCh03	3.9	3.8	3.9	2.3	2.3	2.0	2.3	3.3	2.3	2.2	2.0	3.0	3.0	2.5	2.2	2.5	2.2	57.8	6th	A
StgoCh11	3.9	2.6	3.1	2.0	2.3	1.5	2.4	3.2	2.2	2.3	2.0	3.0	3.0	2.5	2.2	2.9	2.5	58.7	7th	A
StgoCh08	3.9	3.5	3.5	2.3	2.1	1.8	2.4	2.2	2.0	2.5	2.0	3.0	3.0	2.5	2.0	2.5	2.3	59.7	8th	A
StgoCh09	3.9	2.3	3.3	2.5	2.2	1.8	2.1	2.6	1.8	2.3	2.0	3.0	3.0	2.5	2.1	2.5	2.4	60.2	9th	A
StgoCh06	3.9	3.2	3.6	2.3	2.5	1.8	2.4	2.3	2.4	2.4	2.0	3.0	3.0	2.5	2.2	2.5	1.6	60.5	10th	A
StgoCh12	3.9	2.5	3.0	2.5	1.6	1.6	2.4	2.0	1.6	2.6	2.0	3.0	3.0	2.5	2.2	2.6	2.5	61.1	11st	A
StgoCh01	3.9	2.6	3.6	2.2	2.0	1.8	2.3	2.3	2.1	2.3	2.0	3.0	3.0	2.5	2.2	2.2	1.3	63.1	12nd	A

of heritage buildings; (ii) Three input parameters (v_2 [roof design], v_5 [preservation] and r_7 [overloads]) with significant weights in the fuzzy logic model ($FBSL_{2.0}$) have the lowest dispersion valuation during the inspection of the experts. Only r_{17} (occupancy) presents a medium–high dispersion by the experts' valuation; this input variable must be examined in detail in future works; (iii) Four case studies (41.6% of the sample) need priority intervention. These results are matched by the experts consulted in the three scenarios.

The application of methodologies such as that used in this work helps identify protocols that can consider intervention priorities for architectural heritage buildings with constructive similarities. The applied fuzzy method has been tested in South Europe (Spain and Portugal) and on heritage buildings located in Chile's Los Ríos region (Valdivia), Los Lagos region (San Pablo, Osorno, Puerto Octay and Puerto Montt) and the city of Valparaíso (Valparaíso region). This contributes toward economic, envi-

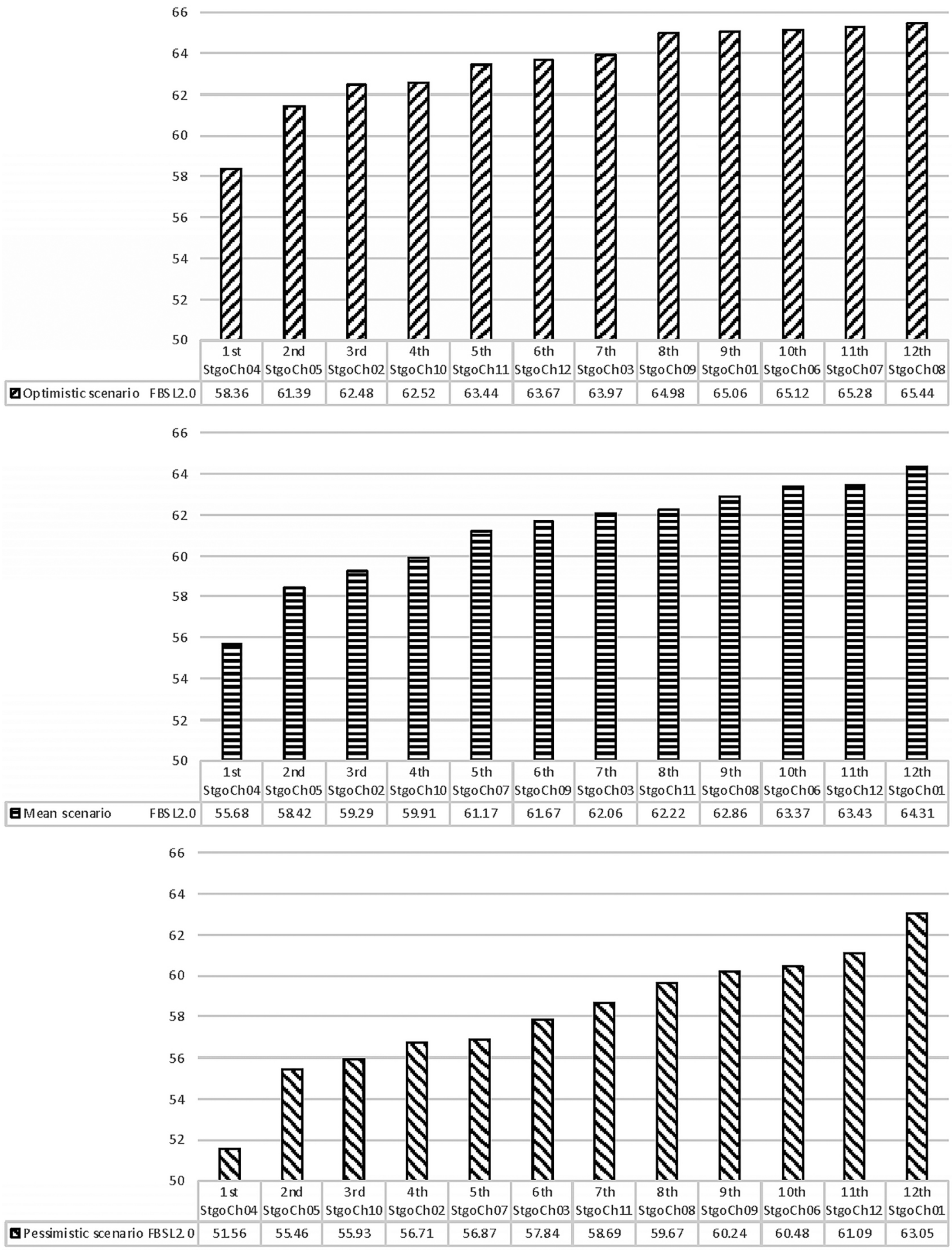

Figure 7. Graphical analysis of the 12 heritage churches' functional performance in the three scenarios modelled during the in-situ visual inspection

ronmental and social policy management that is regionally, publicly and locally oriented to safeguard the cultural values of a community over time (Prieto et al., 2020).

According to the results of the model ($FBSL_{2.0}$), the churches with the most critical functional performance are StgCh04, StgCh05, StgCh02 and StgCh10. The buildings visually present structural anomalies, detachment of some façade elements, stains or colour changes and humidity conditions in the façade, wear or detachment of the first layer, in a large part of it, detachment of elements of the substrate and rotting in a large part of the structure. These heritage buildings have suffered acts of vandalism; some parts of the structures and façades are painted with graffiti, and some stained-glass windows are broken and vandalized.

Conclusions and future research directions

The main impact of the proposed approach is its promotion of new strategies for the preservation of heritage buildings that consider extrinsic hazard parameters and the vulnerabilities of heritage construction. This work involved a panel of seven experts who visually inspected 12 heritage parish churches in Santiago de Chile. This approach is an innovation in that it considers a set of experts in the evaluation of the functional performance of a set of heritage buildings in central Chile.

Considering the input variables of the model, three parameters were identified to have the lowest valuation dispersion during the inspection stage by the experts; two were related to vulnerabilities (v_2 [roof design], v_5 [preservation]), and one was related to external risks (r_7 [overloads]). These variables present significant weights in the fuzzy logic model. In this sense, r_{17} (occupancy) presented a medium–high dispersion of the experts' valuation; thus, this input variable must be examined in detail in future works due to its important weight in the model. Such expert-panel-based approaches can help in the improvement of input variable valuation during inspection.

Regarding the output of the model, cases StgoCh02, StgoCh04, StgoCh05 and StgoCh10 (33.3% of the sample) presented the lowest functional service life in the three scenarios (optimistic, mean and pessimistic). StgCh01, StgCh07 and StgCh12 (25% of the sample) were matched between the mean and pessimistic scenarios. Only one case study (StgoCh03; 8.3% of the sample) was matched between the optimistic and mean scenarios concerning the experts' valuation during the inspection stage. Three case studies (StgoCh01, StgoCh07 and StgoCh12; 25% of the sample) were not matched in any of the three scenarios modelled. Therefore, this type of methodology, which is based on fuzzy logic, supports the management and reduction of the uncertainty in building degradation processes and aids in the reduction of uncertainty during the in-situ inspection of buildings.

The information gained in this study is crucial since the fuzzy set method (digital management) can be applied by different stakeholders (AEC) and different local end-users in the construction sector, thereby promoting an effective method for safeguarding heritage buildings. The computational fuzzy model showed a slight deviation between the expert panel members' in-situ visual inspection. Thus, despite that different experts can evaluate a building in varying ways, the fuzzy logic management methodology implemented helps in the minimization of the process and result uncertainties. These kinds of methodologies also contemplate an innovative contribution concerning the LCA during the occupancy and maintenance stages of heritage buildings emplaced in South Chile. In future research, (i) a particular detailed examination of the valuation of each input parameters of the fuzzy logic should be developed, which would help in a detailed profound understanding of the possible deviation between professional experts' valuations; (ii) the fuzzy method may be adapted concerning new potential circumstances, components and environmental contexts.

Acknowledgements

The authors would like to thank the expert panel for their time and knowledge.

Funding

This paper was also funded by Agencia Nacional de Investigación y Desarrollo (ANID) of Chile throughout the research projects ANID FONDECYT 11190554 and ANID FONDECYT 1201052.

Author contributions

All authors took part in the entire researching process.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Akkurt, S., Tayfur, G., & Can, S. (2004). Fuzzy logic model for the prediction of cement compressive strength. *Cement and Concrete Research*, *34*(8), 1429–1433. https://doi.org/10.1016/j.cemconres.2004.01.020

Augusti, G., Ciampoli, M., & Giovenale, P. (2001). Seismic vulnerability of monumental buildings. *Structural Safety*, *23*(3), 253–274. https://doi.org/10.1016/S0167-4730(01)00018-2

Carpio, M., Martín-Morales, M., & Zamorano, M. (2015). Comparative study by an expert panel of documents recognized for energy efficiency certification of buildings in Spain. *Energy and Buildings*, *99*, 98–103. https://doi.org/10.1016/j.enbuild.2015.04.022

Chai, Y., Jia, L., & Zhang, Z. (2009). Mamdani model based adaptive neural fuzzy inference system and its application in traffic level of service evaluation. *6th International Conference on Fuzzy Systems and Knowledge Discovery* (*FSKD 2009*), *4*, 555–559. https://doi.org/10.1109/FSKD.2009.76

Chandramohan, A., Rao, M. V. C., & Senthil Arumugam, M. (2006). Two new and useful defuzzification methods based on root mean square value. *Soft Computing*, *10*(11), 1047–1059. https://doi.org/10.1007/s00500-005-0042-6

Endsley, M. R. (2000). Errors in situation assessment: Implications for system design BT. In P. F. Elzer, R. H. Kluwe, & B. Boussoffara (Eds.), *Human error and system design and management* (pp. 15–26). Springer London. https://doi.org/10.1007/BFb0110451

Flores-Colen, I., de Brito, J., & de Freitas, V. P. (2006). Expedient in situ test techniques for predictive maintenance of rendered façades. *Journal of Building Appraisal*, *2*(2), 142–156. https://doi.org/10.1057/palgrave.jba.2940047

Hallberg, D. (2009). *System for predictive life cycle management of buildings and infrastructures* [Doctoral thesis. KTH Research School – HIG Centre for Built Environment, University of Gävle]. https://www.diva-portal.org/smash/get/diva2:214580/FULLTEXT01.pdf

Hughes, J. J., & Callebaut, K. (2002). In-situ visual analysis and practical sampling of historic mortars. *Materials and Structures*, *34*(246), 70–75. https://doi.org/10.1007/BF02482103

Ibrahim, F., Harun, S., Samad, A., Hanim, M., Harun, W., & Mariah, W. (2008). Interior semantics of the lobby/waiting area in general hospitals; a preliminary study. In *2nd International Conference on Built Environment in Developing Countries* (*ICBEDC 2008*).

International Organization for Standardization. (2014). *Building construction – Service life planning – Part 4: Service life planning using Building Information Modelling* (ISO Standard No. 15686-4:2014). https://www.iso.org/standard/59150.html

International Organization for Standardization. (2018). *Risk management* (ISO Standard No. 31000:2018). https://www.iso.org/iso-31000-risk-management.html

Jantzen, J. (2015). *Design of fuzzy controllers*. Technical University of Denmark.

Kasal, B., & Anthony, R. W. (2004). Advances in in situ evaluation of timber structures. *Progress in Structural Engineering and Materials*, *6*(2), 94–103. https://doi.org/10.1002/pse.170

Khodeir, L. M., Aly, D., & Tarek, S. (2016). Integrating HBIM (Heritage building information modeling) tools in the application of sustainable retrofitting of heritage buildings in Egypt. *Procedia Environmental Sciences*, *34*, 258–270. https://doi.org/10.1016/j.proenv.2016.04.024

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, *15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130

Macías-Bernal, J. M., Calama-Rodríguez, J. M., Chávez-de Diego, M. J., & Diego, M. J. C. (2014). Modelo de predicción de la vida útil de la edificación patrimonial a partir de la lógica difusa. *Informes de la Construcción*, *66*(533), e006 (in Spanish). https://doi.org/10.3989/ic.12.107

Maliene, V., Dixon-Gough, R., & Malys, N. (2018). Dispersion of relative importance values contributes to the ranking uncertainty: Sensitivity analysis of Multiple Criteria Decision-Making methods. *Applied Soft Computing Journal*, *67*, 286–298. https://doi.org/10.1016/j.asoc.2018.03.003

Marcinkowska, E. (2002). Technical and functional requirements of building deterioration estimation. *Archives of Civil Engineering*, *48*(1), 125–134.

Marôco, J. (2018). *Análise estatística com o SPSS statistics* (7th ed.). Pêro Pinheiro.

Menezes, A., Glória Gomes, M., & Flores-Colen, I. (2015). In-situ assessment of physical performance and degradation analysis of rendering walls. *Construction and Building Materials*, *75*, 283–292. https://doi.org/10.1016/j.conbuildmat.2014.11.039

Meola, C., Di Maio, R., Roberti, N., & Carlomagno, G. M. (2005). Application of infrared thermography and geophysical methods for defect detection in architectural structures. *Engineering Failure Analysis*, *12*(6 Special Issue), 875–892. https://doi.org/10.1016/j.engfailanal.2004.12.030

Ministerio de Vivienda y Urbanismo. (2019). Gobierno de Chile. https://www.minvu.cl/

Pintelon, L., & Van Puyvelde, F. (2006). *Maintenance decision making*. Acco.

Prieto Ibáñez, A. J., Bernal, J. M. M., de Diego, M. J. C., & Sánchez, F. J. A. (2016). Expert system for predicting buildings service life under ISO 31000 standard. Application in architectural heritage. *Journal of Cultural Heritage*, *18*, 209–218. https://doi.org/10.1016/j.culher.2015.10.006

Prieto, A. J., Silva, A., de Brito, J., Macías-Bernal, J. M., & Alejandre, F. J. (2017). Multiple linear regression and fuzzy logic models applied to the functional service life prediction of cultural heritage. *Journal of Cultural Heritage*, *27*, 20–35. https://doi.org/10.1016/j.culher.2017.03.004

Prieto, A. J., Silva, A., de Brito, J., & Macias-Bernal, J. M. (2018). Serviceability of facade claddings. *Building Research & Information*, *46*(2), 179–190. https://doi.org/10.1080/09613218.2016.1264808

Prieto, A. J., Vásquez, V., Silva, A., Horn, A., Alejandre, F. J., & Macías-Bernal, J. M. (2019). Protection value and functional service life of heritage timber buildings. *Building Research and Information*, *47*(5), 567–584. https://doi.org/10.1080/09613218.2017.1404827

Prieto, A. J., Verichev, K., & Carpio, M. (2020). Heritage, resilience and climate change: A fuzzy logic application in timber-framed masonry buildings in Valparaíso, Chile. *Building and Environment*, *174*, 106657. https://doi.org/10.1016/j.buildenv.2020.106657

Riggio, M., Anthony, R. W., Augelli, F., Kasal, B., Lechner, T., Muller, W., & Tannert, T. (2014). In situ assessment of structural timber using non-destructive techniques. *Materials and Structures*, *47*(5), 749–766. https://doi.org/10.1617/s11527-013-0093-6

Rosina, E. (2018). Risk assessment for the conservation of historic buildings: New strategies and tools. In *IFAU 2017-1st International Forum on Architecture and Urbanism* (pp. 114).

Shor, J., & Raz, T. (1988). Assessing the impact of human factors on data processing inspection errors. *Computers & Industrial Engineering*, *14*(4), 503–512. https://doi.org/10.1016/0360-8352(88)90051-4

Silva, A. C. da, Brito, J. de, & Gaspar, P. L. (2016). *Methodologies for service life prediction of buildings: with a focus on façade claddings*. Springer. https://doi.org/10.1007/978-3-319-33290-1

United Nations Educacional, Scientific and Cultural Organization. (2020). https://en.unesco.org/

Vega, D. J. G., Pamplona, D. A., & Oliveira, A. V. M. (2016). Assessing the influence of the scale of operations on maintenance costs in the airline industry. *Journal of Transport Literature*, *10*(3), 10–14. https://doi.org/10.1590/2238-1031.jtl.v10n3a2

Widyaevan, D. A., & Rahardjo, S. (2019). The aesthetic study of eclectic interior design: A case study of Mimiti and One Eighty Coffee Shop Bandung. In *Proceedings of the 5th Bandung Creative Movement International Conference on Creative Industries 2018 (5th BCM 2018)*, *197*, 122–128.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Zadeh, L. A. (1983). The role of fuzzy logic in the management of uncertainty in expert systems. *Fuzzy Sets and Systems*, *11*(1–3), 199–227. https://doi.org/10.1016/S0165-0114(83)80081-5

APPENDIX

Table A1. In-situ visual inspection data of the case study StgoCh01

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.0	2.5	2.0	2.0	2.0	2.2	3.0	0.382	2.0	2.2	3.0
v_3	3.0	1.5	3.0	4.0	1.5	3.0	3.0	0.906	1.5	2.7	4.0
v_4	1.5	1.0	2.0	2.0	2.0	2.0	2.0	0.393	1.0	1.8	2.0
v_5	1.3	1.5	1.7	1.7	2.2	1.8	1.8	0.288	1.3	1.7	2.2
r_6	1.0	1.0	1.0	1.0	2.0	2.0	1.0	0.488	1.0	1.3	2.0
r_7	2.0	2.0	2.0	2.0	2.0	2.5	2.0	0.189	2.0	2.1	2.5
r_8	2.0	1.5	2.0	2.0	2.5	2.0	2.0	0.289	1.5	2.0	2.5
r_9	1.0	1.5	1.0	2.0	2.2	2.0	1.0	0.538	1.0	1.5	2.2
r_{10}	1.3	1.0	2.0	1.0	2.0	2.5	2.0	0.584	1.0	1.7	2.5
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	1.0	2.0	2.0	2.0	2.0	1.0	2.0	0.488	1.0	1.7	2.0
r_{16}	2.0	2.0	1.0	2.0	2.0	1.5	2.0	0.393	1.0	1.8	2.0
r_{17}	1.0	1.0	1.0	1.0	1.0	1.5	1.0	0.189	1.0	1.1	1.5

Table A2. In-situ visual inspection data of the case study StgoCh02

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	1.9	2.8	1.5	2.0	2.4	1.5	2.0	0.467	1.5	2.0	2.8
v_3	2.5	2.5	3.5	4.0	2.6	2.2	3.0	0.643	2.2	2.9	4.0
v_4	2.0	2.0	1.0	1.0	1.4	2	1.5	0.454	1.0	1.6	2.0
v_5	2.5	3.3	2.8	2.7	2.5	2.4	2.7	0.317	2.4	2.7	3.3
r_6	1.0	1.0	1.0	2.0	1.0	2.0	1.0	0.488	1.0	1.3	2.0
r_7	2.0	2.0	2.0	3.0	2.0	2.5	2.0	0.393	2.0	2.2	3.0
r_8	3.0	2.5	2.5	3.0	3.0	2.7	3.0	0.241	2.5	2.8	3.0
r_9	2.0	2.0	2.5	2.5	3.2	2.5	2.0	0.438	2.0	2.4	3.2
r_{10}	1.3	1.0	1.5	3.0	2.4	2.2	2.0	0.694	1.0	1.9	3.0
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	2.0	2.0	2.0	2.0	1.0	2.0	0.378	1.0	1.9	2.0
r_{16}	2.0	2.0	3.0	2.0	2.0	1.5	2.0	0.450	1.5	2.1	3.0
r_{17}	1.0	3.0	2.0	2.0	3.0	2.0	2.0	0.690	1.0	2.1	3.0

Table A3. In-situ visual inspection data of the case study StgoCh03

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	3.0	2.8	2.0	3.6	3.6	4.0	3.0	0.660	2.0	3.1	4.0
v_3	3.0	3.0	3.5	3.2	3.2	4.5	3.0	0.541	3.0	3.3	4.5
v_4	2.0	2.0	2.0	2.0	2.0	2.5	2.0	0.189	2.0	2.1	2.5
v_5	2.0	1.5	2.5	1.8	2.0	2.3	1.9	0.316	1.5	2.0	2.5
r_6	1.0	1.0	1.0	2.0	2.0	2.0	1.0	0.535	1.0	1.4	2.0
r_7	2.0	2.0	2.0	2.0	2.0	2.5	2.0	0.189	2.0	2.1	2.5
r_8	3.0	1.0	2.0	3.0	3.0	2.5	3.0	0.764	1.0	2.5	3.0
r_9	1.5	1.5	2.0	2.0	2.0	2.5	2.0	0.345	1.5	1.9	2.5
r_{10}	1.5	1.0	2.3	1.6	1.6	2.5	1.0	0.571	1.0	1.6	2.5
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	2.0	2.0	2.0	2.0	1.0	2.0	0.378	1.0	1.9	2.0
r_{16}	2.0	2.0	3.0	2.0	2.0	1.5	2.0	0.450	1.5	2.1	3.0
r_{17}	1.0	1.0	2.0	2.0	2.0	2.0	2.0	0.488	1.0	1.7	2.0

Table A4. In-situ visual inspection data of the case study StgoCh04

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	1.5	1.0	2.0	2.2	2.0	2.4	2.0	0.472	1.0	1.9	2.4
v_3	3.0	2.0	3.8	2.0	3.4	2.0	3.0	0.734	2.0	2.7	3.8
v_4	2.0	1.0	2.0	1.4	2.0	2.0	1.5	0.404	1.0	1.7	2.0
v_5	2.3	4.0	3.5	3.3	3.5	3.0	3.2	0.522	2.3	3.3	4.0
r_6	1.0	1.0	1.0	1.0	1.0	1.5	1.0	0.189	1.0	1.1	1.5
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	2.5	1.0	2.5	3.2	2.5	2.5	2.0	0.677	1.0	2.3	3.2
r_9	2.0	4.0	3.8	3.0	3.2	3.0	2.0	0.775	2.0	3.0	4.0
r_{10}	1.0	1.0	2.8	2.2	2.5	2.5	2.0	0.719	1.0	2.0	2.8
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	1.0	1.0	2.0	2.0	2.0	1.0	1.0	0.535	1.0	1.4	2.0
r_{16}	1.0	2.0	4.0	4.0	4.0	1.5	2.0	1.314	1.0	2.6	4.0
r_{17}	1.0	4.0	3.0	3.0	3.0	2.0	3.0	0.951	1.0	2.7	4.0

Table A5. In-situ visual inspection data of the case study StgoCh05

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	3.8	2.8	2.0	3.0	3.5	3.0	3.0	0.567	2.0	3.0	3.8
v_3	4.0	2.0	3.5	2.6	3.8	4.0	3.0	0.767	2.0	3.3	4.0
v_4	2.0	2.0	2.0	1.0	2.0	2.5	1.5	0.476	1.0	1.9	2.5
v_5	2.8	2.6	2.7	2.7	2.5	3.0	2.7	0.157	2.5	2.7	3.0
r_6	1.0	1.0	1.0	1.0	1.0	2.0	1.0	0.378	1.0	1.1	2.0
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	2.0	2.0	2.5	2.6	2.0	2.0	2.0	0.270	2.0	2.2	2.6
r_9	2.4	3.0	2.0	1.8	2.5	2.7	3.0	0.463	1.8	2.5	3.0
r_{10}	1.0	1.0	2.0	2.0	1.0	2.5	2.0	0.627	1.0	1.6	2.5
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	1.0	2.0	2.0	2.0	1.0	2.0	0.488	1.0	1.7	2.0
r_{16}	2.0	2.0	3.0	2.0	2.0	1.5	2.0	0.450	1.5	2.1	3.0
r_{17}	1.0	1.0	2.0	3.0	3.0	2.0	2.0	0.816	1.0	2.0	3.0

Table A6. In-situ visual inspection data of the case study StgoCh06

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	1.8	3.0	2.0	2.8	2.0	3.5	3.0	0.649	1.8	2.6	3.5
v_3	3.0	2.0	3.8	3.6	2.0	3.2	3.0	0.699	2.0	2.9	3.8
v_4	2.0	1.0	2.0	1.8	1.5	2.5	2.0	0.472	1.0	1.8	2.5
v_5	2.1	1.4	2.0	1.7	2.2	2.8	2.0	0.442	1.4	2.0	2.8
r_6	1.0	1.0	1.0	1.0	2.0	2.0	1.0	0.488	1.0	1.3	2.0
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	1.9	1.0	1.5	1.6	2.0	2.7	2.0	0.527	1.0	1.8	2.7
r_9	1.6	1.5	1.0	1.6	2.6	2.5	2.0	0.574	1.0	1.8	2.6
r_{10}	1.0	1.0	2.3	1.6	1.5	2.7	2.0	0.635	1.0	1.7	2.7
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	1.0	2.0	2.0	2.0	1.0	2.0	0.488	1.0	1.7	2.0
r_{16}	2.0	2.0	2.0	2.0	3.0	2.0	2.0	0.378	2.0	2.1	3.0
r_{17}	1.0	1.0	1.0	1.0	2.0	1.5	1.0	0.393	1.0	1.2	2.0

Table A7. In-situ visual inspection data of the case study StgoCh07

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.0	2.5	2.0	2.0	2.0	4.5	2.5	0.913	2.0	2.5	4.5
v_3	2.0	1.0	3.0	2.0	2.0	3.7	2.0	0.864	1.0	2.2	3.7
v_4	1.5	1.0	1.0	1.0	1.5	2.5	2.0	0.577	1.0	1.5	2.5
v_5	1.8	1.3	2.2	2.0	2.0	2.4	2.0	0.349	1.3	1.9	2.4
r_6	1.0	1.0	1.0	1.0	1.0	2.0	1.0	0.378	1.0	1.1	2.0
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	3.2	3.0	3.0	2.8	3.0	2.5	3.0	0.221	2.5	2.9	3.2
r_9	2.0	1.0	1.5	1.8	1.0	2.5	2.0	0.555	1.0	1.7	2.5
r_{10}	1.5	1.0	2.3	1.8	1.0	2.5	2.0	0.594	1.0	1.7	2.5
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	1.0	2.0	2.0	1.0	1.0	2.0	0.535	1.0	1.6	2.0
r_{16}	2.0	2.0	3.0	3.0	2.0	1.5	3.0	0.627	1.5	2.4	3.0
r_{17}	1.0	1.0	1.0	3.0	3.0	2.0	2.0	0.900	1.0	1.9	3.0

Table A8. In-situ visual inspection data of the case study StgoCh08

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.2	2.4	3.3	4.0	2.5	3.0	3.0	0.613	2.2	2.9	4.0
v_3	3.0	2.6	3.5	3.8	2.0	2.6	3.0	0.602	2.0	2.9	3.8
v_4	2.0	2.0	2.0	1.4	2.0	2.5	2.0	0.318	1.4	2.0	2.5
v_5	1.5	1.3	2.0	1.5	1.4	2.5	1.7	0.419	1.3	1.7	2.5
r_6	1.0	1.0	1.0	1.0	1.0	2.5	1.0	0.567	1.0	1.2	2.5
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	2.4	2.0	1.5	2.0	2.0	2.0	2.0	0.261	1.5	2.0	2.4
r_9	1.0	1.0	1.3	2.0	1.2	2.5	1.0	0.593	1.0	1.4	2.5
r_{10}	1.2	1.0	2.5	2.0	1.4	2.7	2.0	0.650	1.0	1.8	2.7
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	1.0	1.0	2.0	2.0	1.0	1.0	2.0	0.535	1.0	1.4	2.0
r_{16}	2.0	2.0	2.0	3.0	2.0	2.0	2.0	0.378	2.0	2.1	3.0
r_{17}	1.0	1.0	1.0	2.0	3.0	1.5	1.0	0.764	1.0	1.5	3.0

Table A9. In-situ visual inspection data of the case study StgoCh09

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.0	2.0	2.0	2.6	2.0	2.2	2.0	0.227	2.0	2.1	2.6
v_3	1.8	2.0	3.5	3.0	2.0	1.7	3.0	0.704	1.8	2.6	3.5
v_4	1.4	2.0	1.0	1.4	3.0	2.5	2.0	0.704	1.0	1.8	3.0
v_5	1.0	1.0	2.0	2.5	1.3	2.0	1.8	0.573	1.0	1.7	2.5
r_6	1.0	1.0	1.0	2.0	1.0	2.0	1.0	0.488	1.0	1.3	2.0
r_7	2.0	2.0	2.0	2.0	2.0	2.2	2.0	0.076	2.0	2.0	2.2
r_8	2.2	1.0	1.3	2.4	2.4	2.5	2.0	0.600	1.0	2.0	2.5
r_9	1.0	1.0	1.3	2.0	1.0	2.0	1.0	0.472	1.0	1.3	2.0
r_{10}	1.8	2.0	1.5	1.8	1.0	2.5	2.0	0.465	1.0	1.8	2.5
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	1.0	1.0	2.0	2.0	2.0	1.0	2.0	0.535	1.0	1.6	2.0
r_{16}	2.0	2.0	2.0	3.0	2.0	1.5	2.0	0.450	1.5	2.1	3.0
r_{17}	1.0	1.0	1.0	2.0	3.0	1.7	2.0	0.745	1.0	1.7	3.0

Table A10. In-situ visual inspection data of the case study StgoCh10

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.2	2.5	2.0	2.4	2.2	2.7	2.5	0.237	2.0	2.4	2.7
v_3	2.0	1.0	3.5	3.0	2.0	2.0	3.0	0.852	1.0	2.4	3.5
v_4	1.0	1.0	1.0	1.0	1.2	2.5	1.0	0.559	1.0	1.2	2.5
v_5	2.1	2.2	2.7	2.3	1.9	2.5	2.3	0.256	1.9	2.3	2.7
r_6	1.0	1.0	1.0	1.0	1.0	2.2	1.0	0.454	1.0	1.2	2.2
r_7	2.0	2.0	2.0	1.0	2.0	2.3	2.0	0.412	1.0	1.9	2.3
r_8	1.8	2.0	2.8	3.0	2.0	2.5	2.0	0.457	1.8	2.3	3.0
r_9	1.4	1.0	2.0	2.0	2.0	2.5	2.0	0.489	1.0	1.8	2.5
r_{10}	1.2	1.0	2.0	1.8	2.5	2.7	2.0	0.623	1.0	1.9	2.7
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	1.0	1.0	2.0	2.0	2.0	1.0	2.0	0.535	1.0	1.6	2.0
r_{16}	2.0	2.0	3.0	4.0	1.0	1.5	3.0	1.029	1.0	2.4	4.0
r_{17}	1.0	3.0	2.0	2.0	3.0	2.0	3.0	0.756	1.0	2.3	3.0

Table A11. In-situ visual inspection data of the case study StgoCh11

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.2	3.0	2.0	2.0	2.0	2.4	2.0	0.373	2.0	2.2	3.0
v_3	2.5	2.0	3.0	3.0	1.5	2.5	3.0	0.577	1.5	2.5	3.0
v_4	1.5	1.0	1.5	1.0	1.5	2.5	1.0	0.535	1.0	1.4	2.5
v_5	2.1	1.9	2.2	1.8	2.2	2.5	2.2	0.211	1.8	2.1	2.5
r_6	1.0	1.0	1.0	1.0	1.0	2.0	1.0	0.378	1.0	1.1	2.0
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	2.0	3.0	3.0	1.8	3.0	2.7	3.0	0.522	1.8	2.6	3.0
r_9	1.5	2.0	1.5	1.8	1.4	2.5	2.0	0.389	1.4	1.8	2.5
r_{10}	2.3	1.0	2.0	1.4	2.0	2.3	2.0	0.483	1.0	1.9	2.3
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	1.0	2.0	2.0	2.0	1.0	2.0	0.488	1.0	1.7	2.0
r_{16}	2.0	2.0	1.0	4.0	1.0	1.5	2.0	1.018	1.0	1.9	4.0
r_{17}	1.0	1.0	2.0	2.0	3.0	2.0	2.0	0.690	1.0	1.9	3.0

Table A12. In-situ visual inspection data of the case study StgoCh12

Id	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	SD	Min	Mean	Max
v_1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	–	–	–	–
v_2	2.3	2.5	2.0	2.0	2.5	2.4	2.0	0.237	2.0	2.2	2.5
v_3	2.0	1.0	3.0	2.0	2.0	3.5	2.0	0.809	1.0	2.2	3.5
v_4	2.0	2.0	1.0	1.0	2.0	3.0	2.0	0.690	1.0	1.9	3.0
v_5	1.1	1.0	1.3	1.7	1.2	1.6	1.5	0.253	1.0	1.4	1.7
r_6	1.0	1.0	1.0	2.0	1.0	1.6	1.0	0.407	1.0	1.2	2.0
r_7	2.0	2.0	2.0	1.0	2.0	2.5	2.0	0.450	1.0	1.9	2.5
r_8	1.4	1.0	1.3	2.0	1.5	2.4	1.0	0.522	1.0	1.5	2.4
r_9	1.2	1.0	1.0	1.4	1.0	2.0	1.0	0.373	1.0	1.2	2.0
r_{10}	2.6	2.5	1.5	1.6	2.4	2.5	2.0	0.458	1.5	2.2	2.6
r_{11}	2.0	2.0	2.0	2.0	2.0	2.0	2.0	–	–	–	–
r_{12}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{13}	3.0	3.0	3.0	3.0	3.0	3.0	3.0	–	–	–	–
r_{14}	2.5	2.5	2.5	2.5	2.5	2.5	2.5	–	–	–	–
r_{15}	2.0	1.0	2.0	2.0	2.0	1.0	2.0	0.488	1.0	1.7	2.0
r_{16}	2.0	2.0	1.0	3.0	2.0	2.0	2.0	0.577	1.0	2.0	3.0
r_{17}	1.0	1.0	1.0	2.0	3.0	2.0	2.0	0.756	1.0	1.7	3.0