VULNERABILITY INDEX: A NEW APPROACH FOR PREVENTIVE CONSERVATION OF MONUMENTS

Rocío Ortiz*, Pilar Ortiz

Universidad Pablo de Olavide, Department of Physical, Chemical and Natural Systems. Carretera de Utrera Km 1, ES-41013 Sevilla, España

* Corresponding author: Rocío Ortiz

E-mail: rortcal@upo.es

ABSTRACT

A new approach is developed for vulnerability analysis of monuments based on a matrix model and the relationships with static and structural factors, climatic conditions, air quality, urban planning and social agents for preventive conservation of cultural heritage in urban centers.

The objective is to provide tools for decision-makers in the current recession to allow them to prioritize strategies for cultural heritage preservation in a town, where territorial policies are applied and regions where restoration budget is distributed. This new tool allow to classify monuments in order to prioritize restoration and is a useful tool in deeper analysis associated to risks assessment.

The degradation of building materials and structures is mainly due to deterioration caused by structural instability, weathering, pollution and anthropogenic damage. The vulnerability approach of each monument (vulnerability indexes) were calculated, based on a Leopold matrix that depends on intrinsic variables and the life of the monuments. For the very first time, the influence of different deterioration agents has been balanced with a Delphi forecast based on architects´ opinions.

The result is a new pre-Artificial Intelligence tool that enables users to reproduce human reasoning to study relations between vulnerability factors, risk factors and the historical parameters of the monuments.

Key words: vulnerability, cultural heritage, preventive conservation, monuments, DELPHI

1. Introduction

Preventive conservation studies the risks of monuments, its aims are a better knowledge of threats (hazards) and the current conservation condition (vulnerability) to minimize further degradation and increase the service life of buildings.

Frequently, unusual environmental conditions, such as earthquakes, floods, fires, etc., have a disastrous impact on the conservation of Cultural Heritage sites. However, the slow degradation of building materials is also brought about by normal conditions, such as pollution, wind erosion, capillarity dampness, etc.

In this respect, two different risk strategies can be found: the first is a continuous action in response to the ravages of time and the second is associated with isolated events. Both cases need a first step with an evaluation of the vulnerability of the building in the face of these agents.

For this reason, thorough knowledge of the conservation state of buildings is firstly required in order to evaluate their response to environmental factors in a deeper analysis of risk assessment performed in a second step.

The vulnerability of buildings has been studied using different methods. Examples of these are the evaluation of the state of conservation/decay of architectural heritage and their interaction with natural-anthropological components through a vulnerability index [1] or by geo-referencing the internal environmental differences within buildings [2].

A concept related to vulnerability is the service life, CIB- W080 (International Council for Research and Innovation in Building and Construction) is progressing towards predicting the life of building materials and elements, through the identification of systematic methodologies related to the evaluation and estimation of the service life [3-6].

The analysis of building types and risk analysis or vulnerability to earthquakes [7-13], tsunamis [13], flooding [14], hurricanes and tornadoes [15-16], is widespread and used to assess post-emergency in most cases, in specific scenarios that we could classify as mono-risk. All these natural hazards must be added to anthropogenic factors, which may also cause serious damage to construction materials and the massive destruction of cultural heritage such as what happened in World War II [17-18]. In addition, street riots or vandalism also generate an added risk and continued losses of historic value, as the latest events in Syria and Iraq [19-20]. Also, the vulnerability is being applied to predictive life cycle analysis for durability study of several materials (facings, stone, concrete, etc.) and architectural elements [21-26], and to compare the sustainability of certain types of construction (residential, hospitals, etc.) [27-28]. Moreover, the vulnerability analysis gradually progresses in diagnosis of architectural heritage [29-33].

Our research assesses the vulnerability as a complex number that depends on multi-hazards assessment of building in the urban environment taken into account the opinion of experts with a DELPHI model [34-35] based on the analysis of materials and conditions, in order to evaluate the monument as a whole with three groups of factors: Quality of materials, Construction and Structure and Anthropogenic factors.

2. Materials and methods

2.1. Study Monuments

The city of Seville is located in southern Spain. Seville has been a Roman, Muslim and Christian city. Its streets and squares in the historical center are clearly influenced by those periods and the main hazards suffered by the city have been floods, earthquakes, wars and urban development.

Today, most of the buildings in the historic center have different levels of protection. The study is based on 30 churches, the first parish churches after recapture in 1248, one of the most emblematic and ancient monuments having been considered when applying the vulnerability analysis (figure 1).

Table 1 summarizes the monuments studied and their style and period of construction. It must be taken into account that the buildings under study are the oldest constructions of Seville. Most of these churches have Gothic-Mudejar architecture with different variations. Other primitive parish churches disappeared and were built in baroque or neoclassical style either after the earthquake of Lisbon or after the Napoleonic occupation.

The predominant materials used in the monuments studied in Seville were bricks, calcarenites, limestones, mortars and marbles [36-37]. In the Gothic-Mudejar churches we find either stonework or brickwork as the vertical supporting structure, horizontal wooden covering with jointed rafters, and a finishing consisting of ceramic tiles on top. We can find these stoneworks coated with mortar and uncoated. The foundations are made with non-stop ditches of bricks or stones. On the pilasters, the foundations are made of brick or stone spread footing.

The rebuilt baroque churches foundations are solved by a ditch through brick or stone, the roof structure is made of stone vaults or plaster under a wood structure.

The studied churches show that the materials used are very similar in both the structure and the construction system. Table 2 shows the location of the materials in buildings under study.

The building materials were previously studied in order to establish the vulnerability to physical-chemical attacks such as pollution or salt crystallization. According to the weathering test, the lithotypes used in Seville are very vulnerable to salt crystallization and the mortar used to repair stones is easily detached; mortar and stones employed in these buildings are also very vulnerable to traffic and salt crystallization according to Ortiz et al. [38-39], Escudero et al. [40] and Ruiz et al. [41].

2.2. Data gathering

Knowledge of the monuments and a study of their environmental conditions are essential for vulnerability assessment. The analysis of each monument in the city was recorded in cataloging files, which were focused on location, era, role played, building materials, general description, restorations, protection under urban development regulations, deterioration patterns and other incidents.

Environmental data was obtained from AEMET (the state meteorological agency) [42], IGME (the Spanish Geological and Mining Institute) [43], OVC (Online Cadaster Office) [44], PGOU (Urbarn Planning of Seville) [45], the Seville City Council Tourism Department [46], REDIAM (the Andalusian Regional Government's Environmental Information Network) [47].

2.3. Vulnerability Analysis

The degradation of building materials and structures is mainly due to deterioration caused by static-structural damage, weathering, pollution and anthropogenic damage. To determine the first vulnerability approach of each monument, the vulnerability index (VI %) was calculated, based on a vulnerability matrix (VM) similar to the one reported by Galán et al. [48] based on a Leopold matrix method for effects and causes [49], but adapted to suit the nature of heritage conservation problems specific to the monuments of Seville.

The vulnerability matrix was prepared by inserting the hazards of this particular area of the city in the rows and the building material characteristics, degree of structural conservation and anthropogenic factors in the columns. Weathering forms were described according to CNR-ICR Normal 1/88 [50], Fitzner [51] and the ICOMOS-ISCS glossary [52]. These characteristics were included in a preliminary classification vulnerability matrix (table 3) according to the methodology previously developed by Ortiz et al. for archeological sites [53] where vulnerability is studied against risk in a deeper study.

Each impact (matrix cell) is described with all the potential weathering forms that could be found in a monument in the city.

The vulnerability matrix for hazards in Seville (Table 3) also includes the study of building simplicity, urban planning protection and level of usage. Buildings with high simplicity are less vulnerable, the vulnerability is higher the more constructive systems (formed by facades, partition walls, roof, covering on floors, ceilings and walls) are in the same building [54]. It is supposed that mixed of materials and different constructive systems can origin material incompatibility, expansion rates of different materials, different structural behaviour, problems in the joints, etc. The measurements of simplicity depend on the design of roof and the diversity of constructive systems, according to the methodology developed by Macias-Bernal et al. [55]

Urban planning protect those monuments with higher historical values, all the monuments under this study are considered with the highest cultural value BIC () and consequently they have been considered with the highest vulnerability value.

The level of usage varies between 1 (minimum vulnerability) in the monuments that are used every day and have maintenance and 5 (maximum vulnerability) those monuments that are abandoned have more possibilities to disappear.

The vulnerability index for the thirty monuments chosen was determined by an on-site study, where the frequency and degree of weathering forms were taken into account. In this study, the index was evaluated for the whole building and the different materials.

The frequency of weathering forms was set between 1 and 3: (a) frequency 1: difficult to detect the presence of the weathering form, (b) frequency 2: weathering form identified easily and (c) frequency3: high rate of occurrence. The degree of weathering was classified into six relative categories, according to the scale used by Fitzner [51]. Level 0 means no damage while levels 1 to 5 range from very low-level damage to very high damage. Table 4 shows the degree of the different weathering forms. Frequency and damage level were combined as shown in table 5 to obtain a numerical value for the intensity of weathering forms in each monument.

After studying the weathering forms, the vulnerability index (VI) was calculated by dividing the total value of the deterioration patterns (V_x) for a monument by the sum of the total value of deterioration patterns in the worst case ($\sum vdp$), when the frequency would be maximum Ortiz et al. [53].

$$VI = \frac{Vx}{\sum_{f=3} vdp} x100 \qquad (1)$$

An expanded vulnerability index that includes building simplicity, urban planning protection and level of usage was developed according to a DELPHI assessment of the influence of different characteristics in the vulnerability matrix:

$VI_e = \sum f_i V_i$

Where:

f_i is associated weighting factor according to DELPHI forecasting

V_i is the vulnerability associated to the variable i

Finally, the expanded vulnerability index (VI%) was classified by degree of vulnerability using ordinal classes as described by Galán et al. [48]: very low (<10%), low (10-25%), moderate (25-50%), high (50-75%) and very high vulnerability (>75%).

2.4. DELPHI analysis of vulnerability factors

It is clear that risk analysis depends on vulnerability as an intrinsic factor and needs the evaluation of cultural heritage experts of different fields and the opinion of the citizens who enjoy and use the monuments or simply visit or live near them. For this reason, research survey has been employed to improve the methodology.

Weighted factors were obtained using the double Delphi process [34-35] by consulting a multidisciplinary group of eight architects and construction engineers with more than 20 years in building restoration for construction vulnerability.

The Delphi weighted value is shown in table 6, which includes the influence of each factor on the vulnerability (%), as well as the mean and standard deviation.

According to experts´ opinion, roof, level of usage and structure, with weights of 88%, 82% and 74% respectively, are the variables that greatly influence on the buildings vulnerability.

Variables such as visual appearance (28%), texture (43%), fire resistance (48%), and urban planning protection (43%) have less than 50% of influence.

The standard deviation varies between 10 and 31, with an average value of 20. Experts have total freedom between 0 and 100 when assessing the factors, which is the cause of the deviation. In any case, they had been consulted in the survey if they considered that the proposed factors affected the vulnerability of the building.

The uncertainty in a quantitative methodology plays a very important role, so it should be known by decision-makers. While evaluations that have low uncertainty should be prioritized according to the magnitude of vulnerability or risk. Moderate and high uncertainty requires a cost-benefit analysis and specific risk research, associates or not to short-term mitigation actions [56]. In our case the standard deviations for each value varies between 10 and 31, since expert opinions and experiences are different, so a cost-benefit analysis is crucial in decision-making.

3. Results and discussion

3.1. Vulnerability analysis

3.1.1. Weathering forms

The weathering forms study is the first step to develop the vulnerability matrix.

The main weathering forms found in Seville (table 7) can be divided into six groups: (a) missing part, loss of painting area and erosion, (b) coloration or discoloration, moist areas, iron-rich patina, soiling, efflorescence, concretion, patina, surface deposit, black crust, and deposit of pigeon droppings, (c) deformation, crack, fracture and fragmentation, (d) differential erosion, sanding, scratching, scaling, detachment, pitting, alveolization, high alveolization and blistering, (e) biological colonization and plant, (f) building works.

The most widely represented weathering forms with the highest frequency found in Seville were missing parts, coloration/ discoloration, moist areas, cracks, vegetation and building work (figure 2). All this damage is associated with lack of maintenance, vandalism or poor-quality interventions. All of them appear in more than 90% of the monuments. Efflorescence, black crust, fractures, blistering and biological colonization appear abundantly in more than 80% of the buildings (figure 3). This damage is associated with capillarity dampness, traffic, the use of incompatible materials and rainfall. The presence of vegetation is abundant in nearly 90% of the monuments and it changes depending on the season.

Weathering forms as erosion (46%), sanding (66%), differential erosion (20%), pitting (13%), alveolization (23%) or high alveolization (53%) are related to stone materials, which is not the predominant material in these buildings. High alveolization, sanding and erosion have been found in abundance, which implies that the external agents that cause these conditions clearly affect the conservation of monuments.

Weathering forms such as pitting, differential erosion, fragmentation, surface deposit, patina and concretions are under 20%, these six patterns are not abundant in the buildings where they appear, except fragmentation in buildings that are very damaged.

Missing painted areas appear in 60% of the churches and this means a loss of artistic value.

Figure 4 summarizes which weathering factors types affect the monuments. The two categories that predominate are discoloration and deposits as well as detachment, followed by loss of material, biological colonization, cracks and deformations, and eventually building works.

The study of deposits and black crusts, show that samples with chemical attack by sulphur oxides are the most common, found in 80% of samples studied, which implies a high influence of SO_2 in the weathering outside the buildings [57]. Pollution is associated with surface deposits and black crust according to former analysis carried out by different techniques (Optical Microscopy, Scanning electron microscopy with X-ray analysis, X-ray diffraction, X-Ray fluorescence, Laser induced breakdown spectroscopy or Laser induced fluorescence) [58-60].

Fires are one of the frequent anthropogenic hazards to cultural heritage; these events usually occur during armed conflicts, after earthquake or may be due to poor maintenance of electric wiring or gas pipeline systems. Hajpál [61] and Gómez-Heras [62] highlighted that the heat of a fire can cause irreversible changes on stones and influence the mineralogical composition, porosity, compressive strength and statical behavior, depending on the lithotypes. Chromatic alterations has been found in the churches that were burnt during

Spanish Civil War (Ominium Sanctorum, Santa Marina, San Gil y San Julián), and could be associated with mineralogical changes and loss of strength [63]. Nevertheless, further studies should be carried out in this regard to evaluate the origin of this damage on-site.

3.1.2. Vulnerability Index

According to the results shown in the cataloging cards, we calculated the vulnerability index (VI%) and expanded vulnerability index (VIe) as it is summarized in figure 5. An analysis of the most significant variables in the calculation for each building is included in figure 6.

The results of the expanded vulnerability index and, consequently, vulnerability degree are shown in figure 5 in comparison with vulnerability index. The monument that is most vulnerable in Seville is Sagrario, with a high degree of vulnerability due to fractures and the loss of vertical position of walls. Another fifteen buildings are moderately vulnerable, such as Magdalena, Anunciación, Santa Cruz, Omnium Sanctorum, Santa Ana and Santa Catalina. La O is the monument with the lowest degree of vulnerability. These results imply that the state of conservation of Sagrario Church makes it more vulnerable than the other monuments to extrinsic factors as earthquake.

The expanded vulnerability index (VIe) allows weighing, those structural variables over aesthetic values or materials. In response to this classification: the church of Sagrario has more than 50% of VIe (high vulnerability), 15 churches have moderate vulnerability (25-50%), 14 churches have low vulnerability (10-25%)

and only one church (La O) has a value under 10% (very low vulnerability). This methodology based on the expanded vulnerability index (VIe) increases the amplitude thereby differentiating the vulnerability degree more clearly.

Figure 6 shows that the structure factors, physicochemical characteristics and constructive system variables are in all the churches with higher influences. The fire resistance and foundation variables have a lower influence, and they are not affecting vulnerability in all the buildings studied.

Figure 7 shows the influence on the vulnerability of those factors related to materials (physicochemical characteristics, texture and fire resistance). In the case of fire resistance, the churches of Sagrario, Magdalena, Anunciación and San Juan de la Palma have values between 25 and 50%. In churches with indoor wooden covering, the poor state of wood and their structural problems would affect negatively if a fire occurs. The texture-structure factor varies between 10 and 20% in 16 churches and only the Magdalena, Santa Ana and Sagrario exceed 15%. The factor related to the physicochemical characteristics varies between 3.5% and 33.5%. The churches of San Lorenzo, El Salvador, San Esteban, Santa Isabel, Santa Marina, Santa Catalina, Santa Ana, Omnium Sanctorum, Anunciación and Magdalena have the highest values (25-35%).

The influence of structural system factors (foundation, structure and building system) are reflected in figure 8. The vulnerability of the structure and foundation of the church of Sagrario is the highest in all the buildings studied.

Regarding the foundation assessment, Anunciación, Magdalena, Omnium

Sanctorum and San Juan de la Palma are affected over 20%. The construction system affects between 20% and 30% in 13 churches and just over 30% in the case of Sagrario due to the problems of loss of vertical position of walls, fragmentation and fractures presented in this building. The structural factor is one of the highest influences in all churches; Sagrario is above 60% and above 30% in the churches of the Magdalena, Santa Maria la Blanca and Anunciación. All those churches have structural problems and should be considered for a first intervention to reinforce the structures because in case of an earthquake they would be more vulnerable than other churches facing up to the horizontal action introduced by an earthquake.

Considering the influence of the factors listed in figure 9 (simplicity of the constructive solution, level of use and cataloging), cataloging is the same for all the buildings studied, since all have a complete protection; the maximum protection given by the PGOU [45] and PEPCH [64].

Regarding the level of usage, all the churches except San Juan de la Palma, San Martin, Santiago and Santa Marina, are used daily as they are Parish and have daily services. However the four churches that are not parish are home to Holy-Week Brotherhoods and have mass weekly. In the churches of the Convents (Santa Isabel and Santa Ines) it was considered weekly use. It highlights the case of Santa Catalina above 80% since this church was closed to worship and without use since 2004 and during these almost 10 years its vulnerability condition has worsened. It is currently under restoration.

Considering the constructive simplicity, the Mudejar churches have a lower percentage (32%) than the Baroque or neoclassical (47%) churches. Constructive simplicity of the former is higher mainly due to the constructive approach adopted in its covers. Some Mudejar churches of the last stage (San Martin and Santa Ana), as well as those who have suffered strong transformations and additions throughout their history (Santiago, San Andres, Santa Ines) have more complex constructive solutions.

The results are summarized in table 8, where the vulnerability of monuments is included. The monuments with moderate or high vulnerability must be carefully monitored in deeper risk analysis for earthquake, soil or fire hazards and the inspections must be included in this database to update the analysis.

Priorities defined by ICCROM-CCI-ICN [55] to assess the magnitude of risk and uncertainty can be applied to decision making in this vulnerability model, understanding the moderate uncertainty according to the standard deviation data obtained from the experts´ opinions. The valuation of the index of vulnerability combined with the feasibility and costs of risk reduction, lead us to qualify priorities according to table 9. Table 9 shows the vulnerability degree and the number of monuments for each action or study according to the results and the maintenance and urban policies recommendations with periods for intervention and inspection. In grey shadow it is highlighted the actions for the building in Seville according to DELPHI uncertainty.

Risk mitigation prioritized by cost-benefit analysis of mitigation strategies, research and further risk analysis, especially for earthquake, must be carried out in Sagrario in a short period as it is the only monument with high vulnerability, meanwhile, cost-benefit analysis of research and further risk analysis is advisable on the fifteen churches with moderate vulnerability. Intervention plans and deeper studies should be carried out in buildings with a higher vulnerability index, mainly due to structure as Sagrario. The vulnerability of the materials (calcites, calcarenites, sandstones, mortars and bricks) is medium-high to anthropogenic hazards (pollution) or percolation and underground water. It is advisable a database for accelerating weathering test for mortars and stones, as they are similar in different buildings.

Underground water must be reduced in each building by on-site research studies and control of capillarity dampness; meanwhile water percolation could be minimized with a yearly preventive surveillance and maintenance plan for all the buildings.

The cleaning of surface deposits involves a huge outlay on restoration that could be decreased if traffic is minimized in historic towns and near emblematic monuments. Traffic effect should be minimized with measures such as creating new pedestrian streets in the historical center.

The cataloguing files and vulnerability calculation must be updated in case of changes or interventions, and it is advisable at least every three years or after a disaster such us floods, fires, earthquake, etc.

4. Conclusions

This paper presents a new tool based on interdisciplinary approach and multi-scenario analysis of vulnerability in buildings in order to develop global urban conservation strategies or preventive maintenance that can minimize the damage to cultural heritage and reduce the cost of isolated interventions with urban plans to implement complementary policies of preventive conservation in different buildings.

This methodology is easy and cost-effective to determine the vulnerability of monuments in a city as a comparison of building state of conservation. The approach provides tools that help to decide preventive conservation actions, and those factors that should be prioritized in deeper studies or conservation efforts and which monuments require clear intervention plans in short periods. This vulnerability study involves an on-site diagnosis analysis balanced by expert´s opinion and requires an adapted protocol for singular buildings.

In the case of study, Seville (Spain), the monuments have different level of conservation, from well-preserved to highly vulnerable. The most vulnerable monument studied is Sagrario Church, which is highly vulnerable due to the fragmentations, fractures and the loss of vertical position of walls. Fifteen buildings show moderate vulnerability and the others low or very low vulnerability. Sagrario Church is very vulnerable to extrinsic factors, especially in the case of a new earthquake so further studies and interventions are recommended in a short period. Moreover, this methodology allow to stablish the period of inspection, the priority of interventions and urban policies that could reduce the cost of heritage restoration for each group.

The novelty of this approach is a transversal development that includes urban, architectural, cultural heritage value, and the analysis of environmental and socio-demographic situation around the monuments weighted by experts opinions as a pre-artificial intelligence tool. This methodology allows to stablish the policies and intervention for a group of monuments in a historical center. Nevertheless, further analysis are recommended to map the main hazards in each city and in case of high degree of vulnerability.

ACKNOWLEDGEMENTS

This paper has been supported and based on the Methodology developed by two Projects: RIVUPH, an Excellence Project of Junta de Andalucia (code HUM-6775), and Art-Risk, a RETOS project of Ministerio de Economía y Competitividad (Gobierno de España). Part of the research has been carried out thanks to the grant of Rocío Ortiz from Cei-Patrimonio UN-10.

REFERENCES

[1] M. Lazzari, M. Danese, N. Masini, A new GIS-based integrated approach to analyse the anthropic-geomorphological risk and recover the vernacular architecture, Journal of Cultural Heritage 10S (2009) e104-e111.

[2] R. Cataldo, A. De Donno, G. De Nunzio, G. Leucci, L. Nuzzo, S. Siviero, Integrated methods for analysis of deterioration of cultural heritage: the Crypt of "Cattedrale di Otranto", Journal of Cultural Heritage 6 (2005) 29–38.

[3]. Haagenrud, S. E. 2004. "Factors causing degradation. Guide and bibliography to service life and durability research for buildings and components", Joint CIB W80/RILEM TC 140 - Prediction of Service Life of Building Materials and Components 2 (1–2): 105.

[4]. Lacasse, M. A., C. Sjostrom. 2005. "Advances in methods for service life prediction of building materials and components"—final report— activities of the CIB W80. In: 10th International Conference on Durability of Building Materials and Components (DBMC), Lyon, France.

[5]. Lacasse, M. A. 2008. "Advances in service life prediction—an overview of durability and methods of service life prediction for non-structural building components". In: Annual Australasian Corrosion Association Conference, Wellington, New Zealand, pp. 1–13.

[6]. Daniotti B, Cecconi FR. Test methods for service life prediction - state of the art report on accelerated laboratory test procedures and correlation between laboratory test procedures and service life data. W080 - prediction of service life

of building materials and components. International Council for Research and Innovation in Building and Construction, Rotterdam, 2010.

[7]. Morales Esteban, A. Peligrosidad sísmica. Leyes de atenuación y análisis de las series temporales de los terremotos. Aplicación al Tajo de San Pedro de la Alhambra de Granada. (in Spanish) (PhD Thesis) Universidad de Sevilla, Sevilla, Spain, 2009.

[8]. González-Drigo, R., A. Avila-Haro, A. H. Barbat, L. G. Pujades, Y. F. Vargas, S. Lagomarsino, and S. Cattari. 2015. "Modernist unreinforced masonry (URM) Buildings of Barcelona: seismic Vulnerability and risk assessment". International Journal of Architectural Heritage 9 (3): 214-230.

[9]. Parisi, M. A., C. Chesi, C. Tardini, and M. Piazza. 2008. "Seismic Vulnerability and Preservation of Timber Roof Structures". In: 6th International Conference on Structural Analysis of Historical Construction; Bath, England; p. 1253-1260.

[10]. Park, K. W., and S. Y. Ok. 2015. "Modal-space reference-model-tracking fuzzy control of earthquake excited structures". Journal of Sound and Vibration 334: 136-150.

[11]. Lantada. N., L. G. Pujades, and A. H. Barbat. 2009. "Vulnerability index and capacity spectrum based Methods for urban Seismic Risk Evaluation. A Comparison Analyses of Masonry Buildings." Natural Hazards 51 (3): 501-524.

[12]. Maqsood, S. T., and J. Schwarz. "Building Vulnerability and Damage during the 2008 Baluchistan Earthquake in Pakistan and Past Experiences." 2010.

Seismological Research Letters 81: 514-525.

[13]. Mück, M., H. Taubenböck, J. Post, S. Wegscheider, G. Strunz, S. Sumaryono and F. A. Ismail. 2012. “Assessing building vulnerability to earthquake and tsunami hazard using remotely sensed data.” Natural Hazards 68 (1): 97-11.

[14]. Wen-Chun, L., T. Ting-Chi, and H. Chih-Hao. 2012. “Building vulnerability to debris flows in Taiwan: a preliminary study.” Natural Hazards 64 (3): 2107-2128.

[15]. Davidson, R., H. Zhao, and V. Kumar. 2003. “Quantitative Model to Forecast Changes in Hurricane Vulnerability of Regional Building Inventory”. Journal of Infrastructure Systems 9 (2): 55-64.

[16]. Wehner, M., J. Ginger, J. Holmes, C. Sandland, and M. Edwards. 2010 Development of methods for assessing the vulnerability of Australian residential building stock to severe wind. In: 17th National Conference of the Australian Meteorological and Oceanographic Society, Canberra, Australia.

[17]. Convención para la Protección de los Bienes Culturales en Caso de Conflicto Armado. Unesco, La Haya, 1954.

[18]. Ascherson, N. Cultural destruction by war and its impacto in Group identities. Cultural Heritage in Postwar Recovery. ICROM conservation Studies. Forum held on October 4-6, 2005. Nicholas Stanley-Price, Editor, 2007, 17-25.

[19]. War in Iraq -Memory and Heritage of the World in Danger. Icomos Heritage at risk 2002-2003, Paris 06.03.2003. http://www.icomos.org/risk/2002/irak-appealesp.htm

[20]. Safeguarding Syrian Cultural Heritage. UNESCO web site.

http://www.unesco.org/new/en/safeguarding-syrian-cultural-heritage/

[21]. Barbuta, M., R. Diaconescu, and M. Harja. 2012. “Using Neural Networks for Prediction of Properties of Polymer Concrete with Fly Ash”. Journal of Materials in Civil Engineering 24 (5): 523-528.

[22]. Gaspar, P. L., and J. de Brito. 2008. “Service life estimation of cement-rendered facades”. Building Research & Information 36(1): 44-45.

[23]. Silva, A., J. De Brito, and P. L. Gaspar. “Application of the Factor Method to Maintenance Decision Support for Stone Cladding.” 2012. Automation in Construction 22 (3): 165–174.

[24]. Shohet, I., and M. Paciuk. 2004. “Service Life Prediction of Exterior Cladding Components under Standard Conditions”, Journal of Construction Management and Economics 22 (10): 1081–1090.

[25] L. Gonçalves, C. C. Fonte, E. N. B. S. Júlio, and M. Caetano. 2009. “Assessment of the state of conservation of buildings through roof mapping using very high spatial resolution images”. Construction and Building Materials 23 (8): 2795-2802.

[26] M. Indirli. 2009. Organization of a Geographic Information System (GIS) database on natural hazards and structural vulnerability for the historical center of San Giuliano di Puglia (Italy) and the City of Valparaiso (Chile). International Journal of Architectural Heritage, Conservation, Analysis and Restoration. Volume 3, Number 4, October-December, Taylor&Francis.

[27]. Kirkham, R. J., and H. Boussabaine. 2005. “Forecasting the residual service life of NHS hospital buildings: a stochastic approach”. Construction Management and Economics 23 (5): 521–529.

[28]. Rincón, L., G. Pérez, and L. F. Cabeza. 2013 "Service Life of the Dwelling Stock in Spain." International Journal of Life Cycle Assessment 18 (5): 919-925.

[29]. Chávez-Hernández, J. A., C. A. Recarey, M. M. García-Lorenzo, and O. López-Jiménez. 2012. “Utilización de la inteligencia artificial en el diagnóstico patológico de edificaciones de valor patrimonial”. Informes de la Construction 64: (527): 297-305.

[30]. Daniotti, B, S. L. Spagnolo. 2007. Service life prediction for buildings’ design to plan a sustainable building maintenance. In: International Conference on Sustainable Construction, Materials and Practices; Lisbon, Portugal p. 515-521.

[31]. Vieira, S. M., A. Silva, J. M. C. Sousa, J. de Brito and P. L. Gaspar. 2015. “Modelling the service life of rendered facades using fuzzy systems.” Automation in Construction 51: 1-7.

[32] R.P. Borg, M. Indirli, F. Romagnoli, C. Rochas, T. Kuznecova, 2014. The ANDROID Case Study; Venice and its Territory: Vulnerability and Resilience in Multi-hazard Scenarios, Procedia Economics and Finance, 11/2014; 18:825 – 836.

[33] MOVE, 2011. EU Project MOVE, “Methods for the improvement of vulnerability assessment in Europe”.

[34] E. Astigarraga, El método Delphi, Unviersidad de Deusto, San Sebastián, 2002.

[35] T. J. Gordon. The Delphi Method, Futures Research Methodology Version 1.0. Sec. 5ª, The Milleninum Project. American Council for the United Nations University, Jerome C. Glenn, Editor, Washington, 1994.

[36] R. Ortiz, P. Ortiz, M.S. Abad, J.M., Martin, M.A Gomez, M.A. Vázquez. "Estudios Estratigráficos de Costras y depósitos en Templos del Casco Histórico de Sevilla." PH, 83, 50-61. España, 2012, ISSN.1136-1867.

[37] F. Colao, R. Fantoni, P. Ortiz, M.A. Vázquez, J.M. Martín, R. Ortiz, N. Idris. Quarry Identification of Historical Building Materials by Means of Laser Induced Breakdown Spectroscopy, X-Ray Fluorescence And Chemometric Analysis. Spectrochimica Acta Part B 65 (2010) 688–694.

[38] P. Ortiz, M.A. Guerrero, M.A. Vázquez; R. Ortiz; J.M. Martín; M.C. Peña. Accelerated weathering test as environmental behaviour trials on calcareous stone. Proceeding 11th International Congress on Deterioration and Conservation of Stone. Tomo I, 223-232. Jadwiga W. Lukaszewicz, Piotr Niemcewicz, Polonia, 2008.

[39] Ortiz, R. Ortiz, P., Martín, J.M., and Vázquez, M.A. 2016. A new approach to the assessment of flooding and dampness hazards in cultural heritage, applied to the historic centre of Seville (Spain). Sci. Total Environ., 551-552: 546-55

[40] C. Escudero, P. Ortiz, R. Ortiz, J.M. Martín, M.A. Vázquez, M.A. Gómez. Análisis del Estado de Conservación de la Iglesia de Omnium Sanctorum (Sevilla).

MACLA nº 15, 81-82. 2011.

[41] M.L. Ruiz, P. Ortiz, R. Ortiz, J.M. Martín, M.A. Vázquez, M.A. Gómez, Estado de Conservación de la Fachada de la Iglesia de Santa Cruz (Sevilla). MACLA nº 15, 185-186. 2011.

[42] Agencia Estatal de Meteorología. http://www.aemet.es.

[43] Instituto Geológico y Minero de España. http://www.igme.es.

[44] Sede Electrónica de la Dirección General del Catastro. https://www.sedecatastro.gob.es/

[45] Plan General de Ordenación Urbanística de Sevilla. Ayuntamiento de Sevilla. Gerencia de Urbanismo. Ayuntamiento de Sevilla. http://www.sevilla.org/urbanismo/

[46] Delegación de Turismo. Ayuntamiento de Sevilla. http://www.sevilla.org/ayuntamiento/areas/area-de-empleo-economia-fiestras-mayores-y-turismo

[47] Red de Información Ambiental. Junta de Andalucía. http://www.juntadeandalucia.es/medioambiente/site/rediam

[48] E. Galán, J.B. Gonzalez, R.M. Ávila. La aplicación de la evaluación de impacto ambiental en el patrimonio monumental y el desarrollo sostenible de las ciudades, Revista de Enseñanza Universitaria, Extraordinario (2006) 123-140.

[49] Leopold, L.B., Clarke, F.E., Hanshaw, B.B., Balsey, J.R., 1971. A procedure for evaluating environmental impact. US Geological Survey Circular 645, Washington DC.

[50] CNR-ICR Normal 1/88. Alterazioni Macroscopiche dei Materiali Lapidei: Lessico, Istituto Centrale per il Restauro (1988) 1-21.

[51] B. Fitzner, Evaluation and documentation of stone damage on monuments. International Symposium of Stone Conservation, Seoul, May 29, Korea, 2007, pp. 25-30.

[52] ICOMOS-ISCS, International Council on Monument and Sites- International Scientific Committee for Stone, Illustrated glossary on stone deterioration patterns, Champign/Marne, Ateliers 30 Impresión, France, 2008.

[53] Ortiz, P., Antunez, V., Martín, J.M., Ortiz, R., Vázquez, M.A., Galán, E. 2014. Approach to environmental risk analysis for the main monuments in a historical city. Journal of Cultural Heritage 15: 432-440. http://dx.doi.org/10.1016/j.culher.2013.07.009

[54] Macías-Bernal, J.M. Modelo de Predicción de la Vida útil de un Edificio: Una aplicación de la lógica difusa. (in Spanish) (PhD Thesis) Universidad de Sevilla, 2012.

[54] Macías-Bernal, J.M., Calama-Rodriguez, J.M., Chávez-de Diego, M.J. 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 doi:10.3989/ic.12.107 -

[56] ICCROM -CCI –CIE. 2007. Curso de evaluación de riesgos ICCROM -CCI- CIE, celebrado en Sibiu, Rumania.

[57]. Ortiz Calderón, M. R. Análisis de vulnerabilidad y riesgos en edificios singulares de Sevilla. (in Spanish) (PhD Thesis) Universidad Pablo de Olavide,

Sevilla, 2014.

[58] Ortiz, P., Ortiz, R., Martín, J.M., Vázquez, M.A., Ctvrtnickova, T., Mateo, M.P., Nicolas, G., Gómez, A. 2013. Characterization of crust and deposits found in churches of Seville. 8TH International Symposium on the conservation of monuments in the Mediterranean Basin. B, 116 - 130.

[59] P. Ortiz, M.A. Vázquez, R. Ortiz, J.M. Martín, T. Ctvrtnickova, M.P. Mateo, G. Nicolas. 2010. Investigation of Environmental Pollution Effects on Stone Monuments in The Case of Santa Maria La Blanca, SEVILLE (SPAIN). Appl Phys A 100: 965–973.

[60] Ortiz, P.; Ortiz, R.; Vazquez, MA; Martin, JM; Colao, F; Fantoni, R. 2014. Laser induced fluorescence applied to diagnosis in calcareous stones. Science, Technology and Cultural Heritage, 263-266. 2014.

[61] M. Hajpál. Heat Effect By Natural Stones used by Historical Monuments. Proceeding 11th International Congress on Deterioration and Conservation of Stone. Tomo I, 137-144. Jadwiga W. Lukaszewicz, Piotr Niemcewicz, Polonia. 2008.

[62] M. Gómez-Heras, M. Procesos y formas de deterioro térmico en piedra natural del patrimonio arquitectónico, UCM, Servicio de Publicaciones, Madrid, 2006.

[63] R. Ortiz, P. Ortiz, J.M. Martín, C. Escudero, M.A. Vázquez. Analysis of heat effects due to fires on calcareous stones. Science and Technology for the Conservation of Cultural Heritage. 139-142. 2013.

[64] Plan Especial de Protección del Conjunto Histórico. Sector 1. San Gil-Alameda. Aprobación definitiva 30/12/2003. Sector 10. Macarena. Aprobación definitiva 29/05/2002. Sector 13. Arenal. Aprobación definitiva 29/05/2007. Sector 13.1. Casa de la Moneda. Aprobación definitiva 03/02/2006. Sector 13.2. Plaza de Armas. Aprobación definitiva 08/02/2001. Sector 14. Triana. Aprobación definitiva 05/11/1999. Sector 16. San Julián-Cruz Roja. Aprobación definitiva 23/04/2002. Sector 2. San Luis. Aprobación definitiva 29/03/2007. Sector 3. Santa Paula-Santa Lucía. Aprobación definitiva 13/09/2000. Sector 4. Santa Catalina-Santiago. Aprobación definitiva 28/09/2012. Sector 5. San Bartolomé. Aprobación definitiva 07/02/2005. Sector 6. Reales Alcazares. Aprobación definitiva 01/06/2012. Sector 7. Catedral. Aprobación provisional 13/12/2013. Sector 8.1. Encarnación-Magdalena. Aprobación definitiva 09/04/2011. Sector 8.2. San Andrés-San Martín. Aprobación definitiva 29/11/2013. Sector 8.3. El Duque-Salvador. Aprobación definitiva 12/01/2012. Sector 8.4. Magdalena. Aprobación definitiva 30/10/2013. Sector 9. San Lorenzo-San Vicente. Aprobación definitiva 18/05/2001. Sector 9.1 Los Humeros. Aprobación definitiva 26/10/1999.

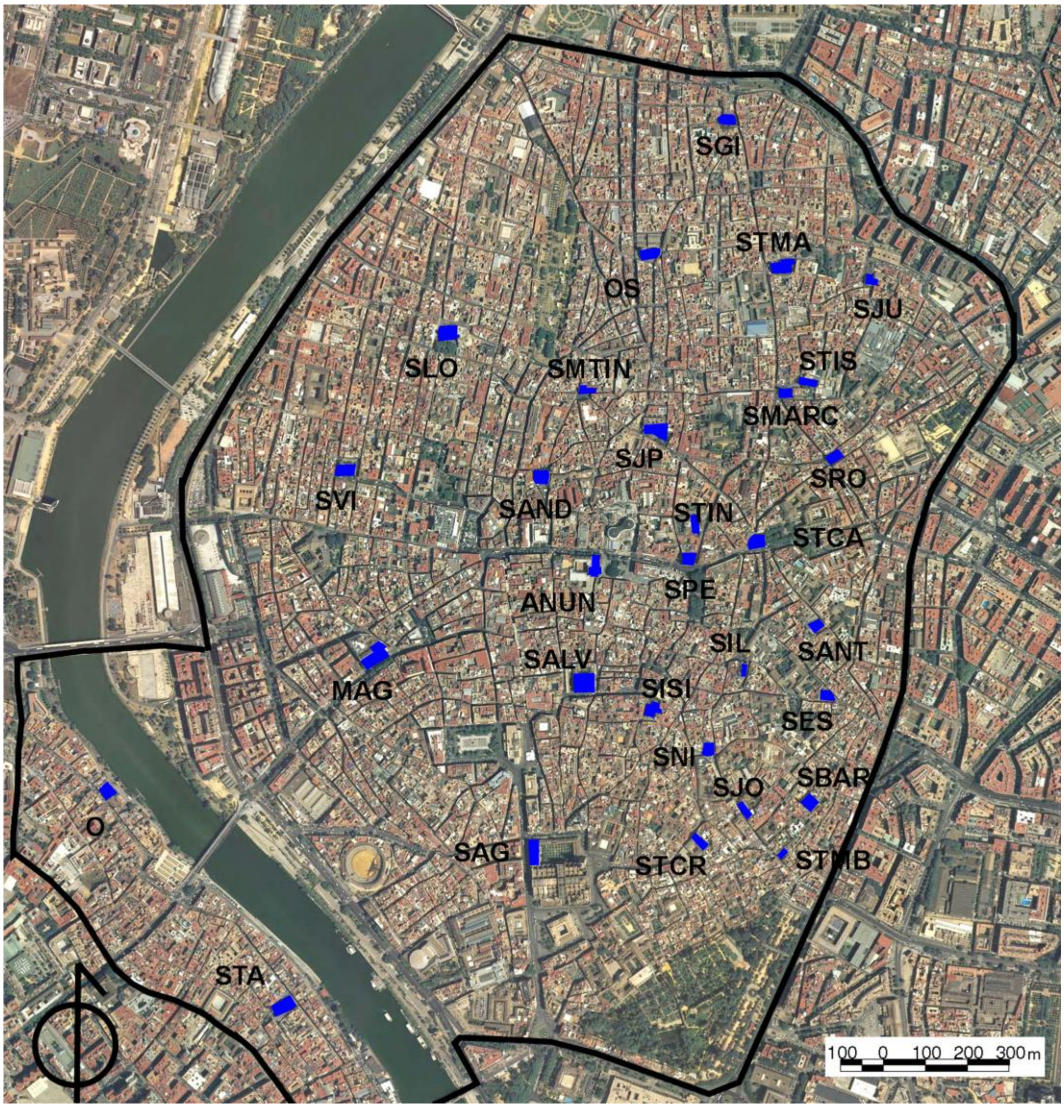


Figure 1. Location of the 30 churches studied in the center of Seville.

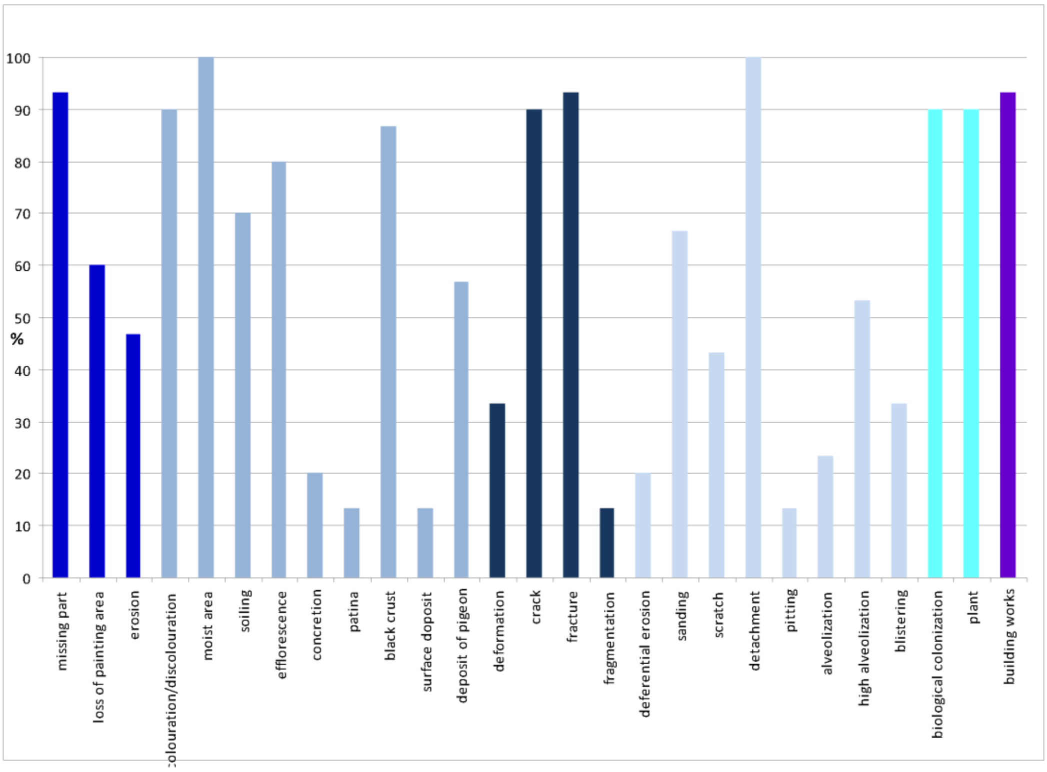


Figure 2. Percentage of weathering forms observed in singular buildings.

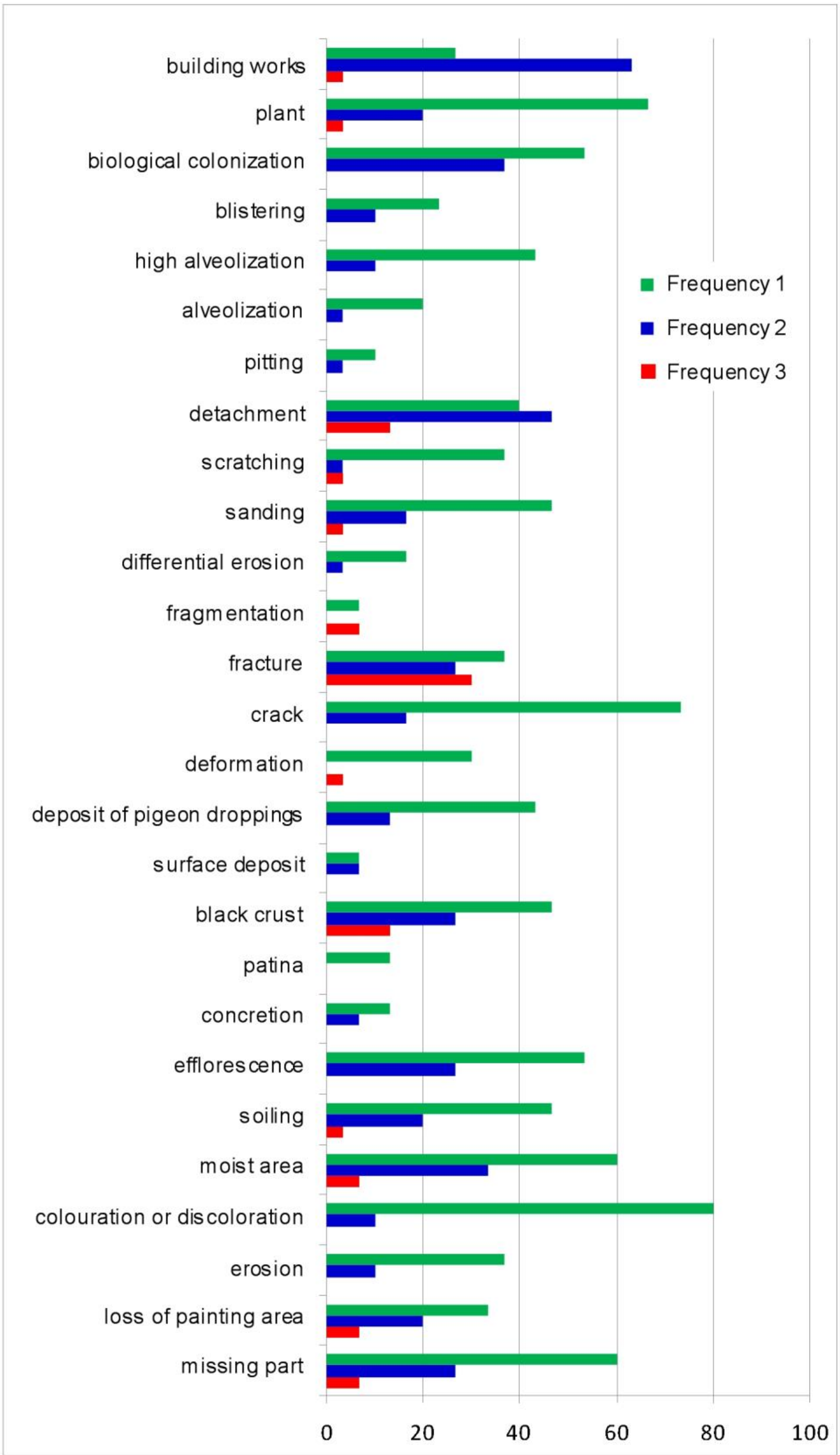


Figure 3. *Percentage of appearance of weathering forms observed in singular buildings according to the frequency.*

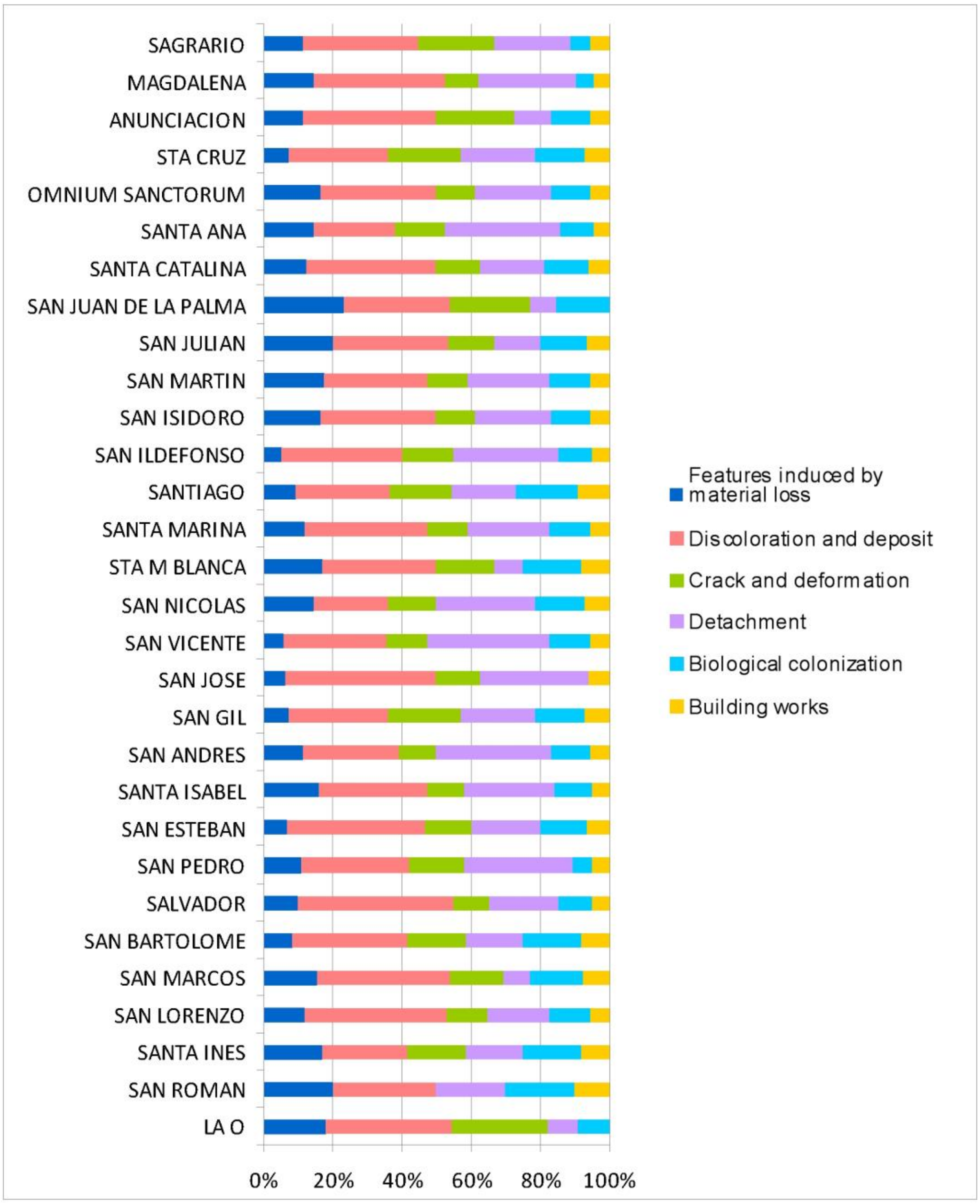


Figure 4. Percentage of weathering factors types affecting each singular building.

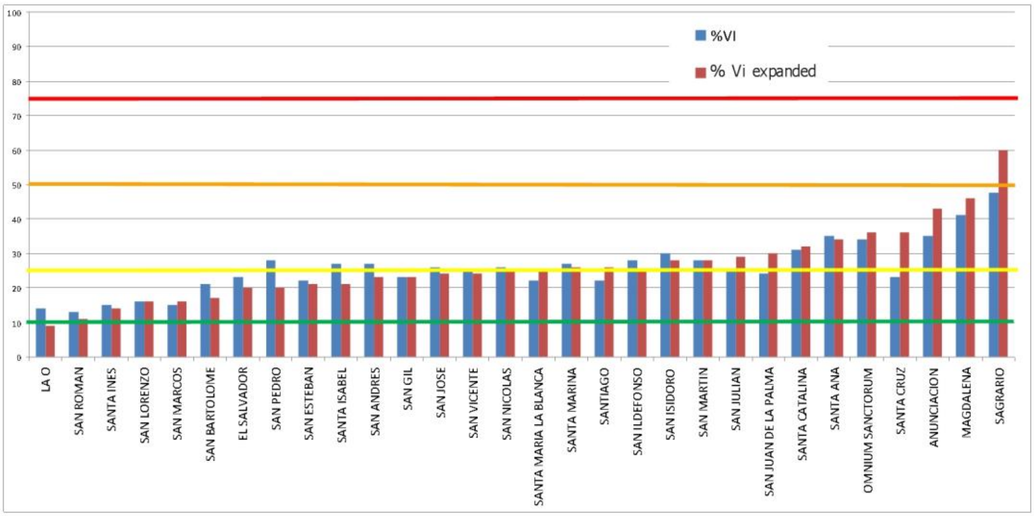


Figure 5. Vulnerability index and expanded vulnerability index for the 30 churches studied.

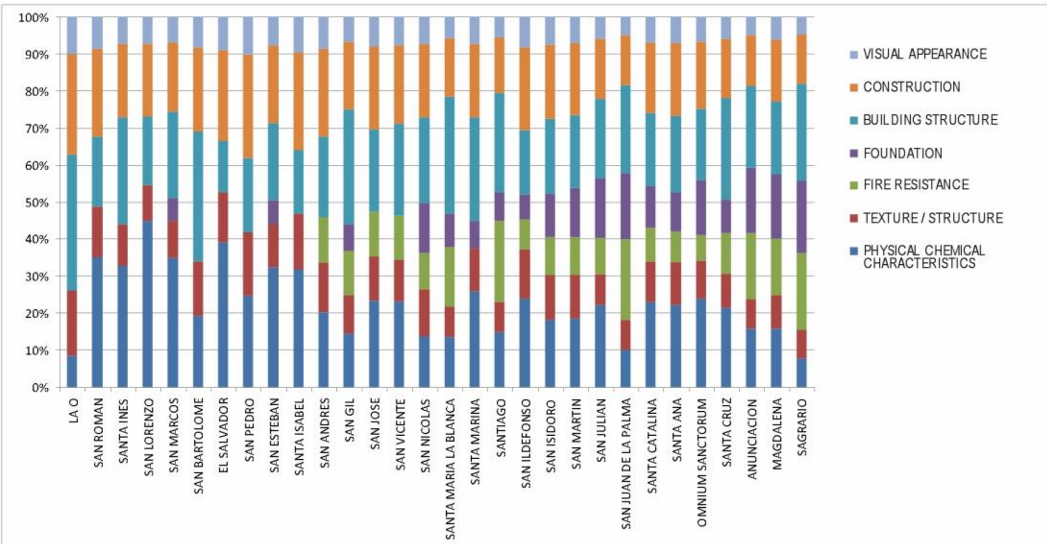


Figure 6. Influence of different factors in the expanded vulnerability index for the 30 churches studied.

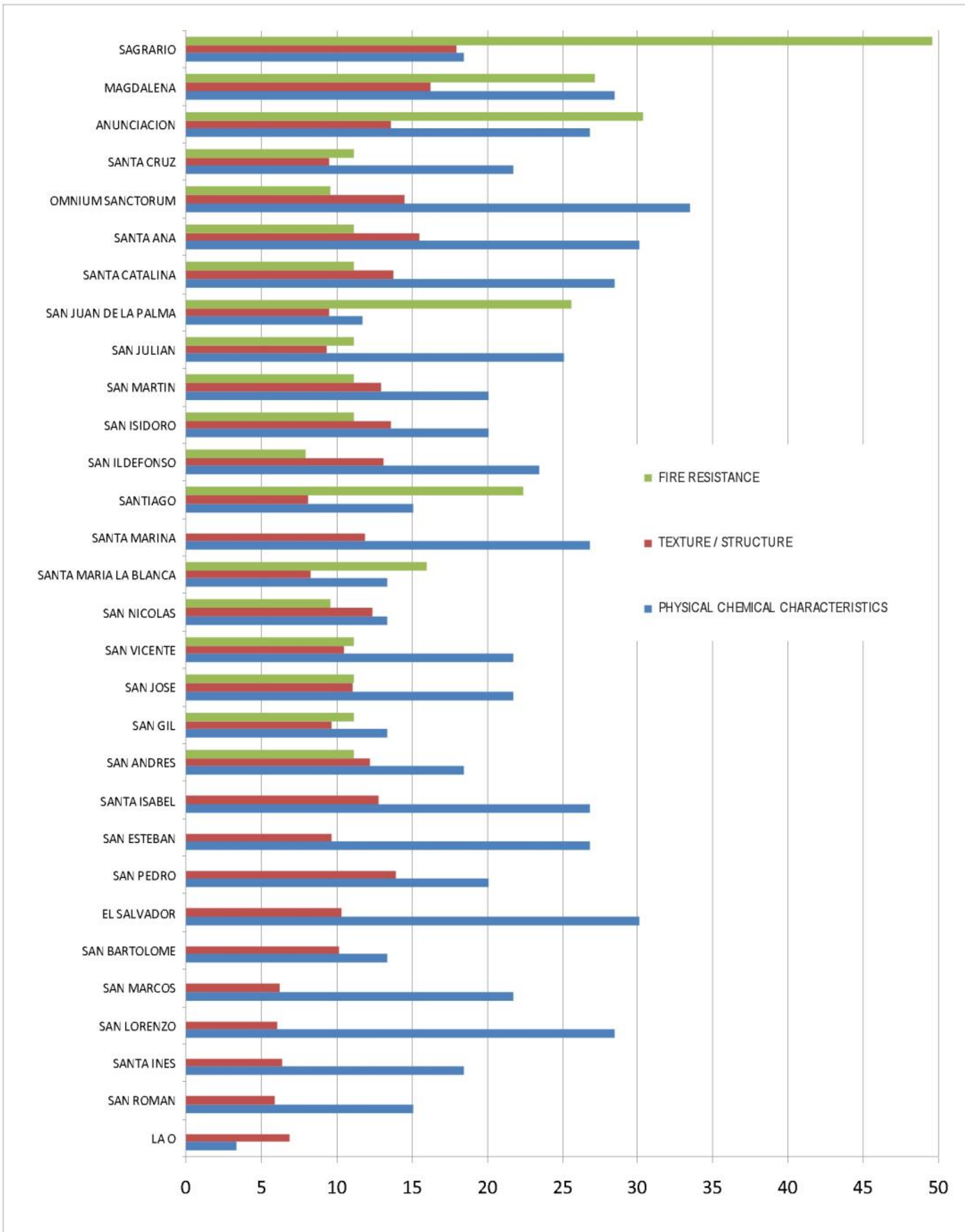


Figure 7. Influence of the factors related to materials on the expanded vulnerability index for the 30 churches studied.

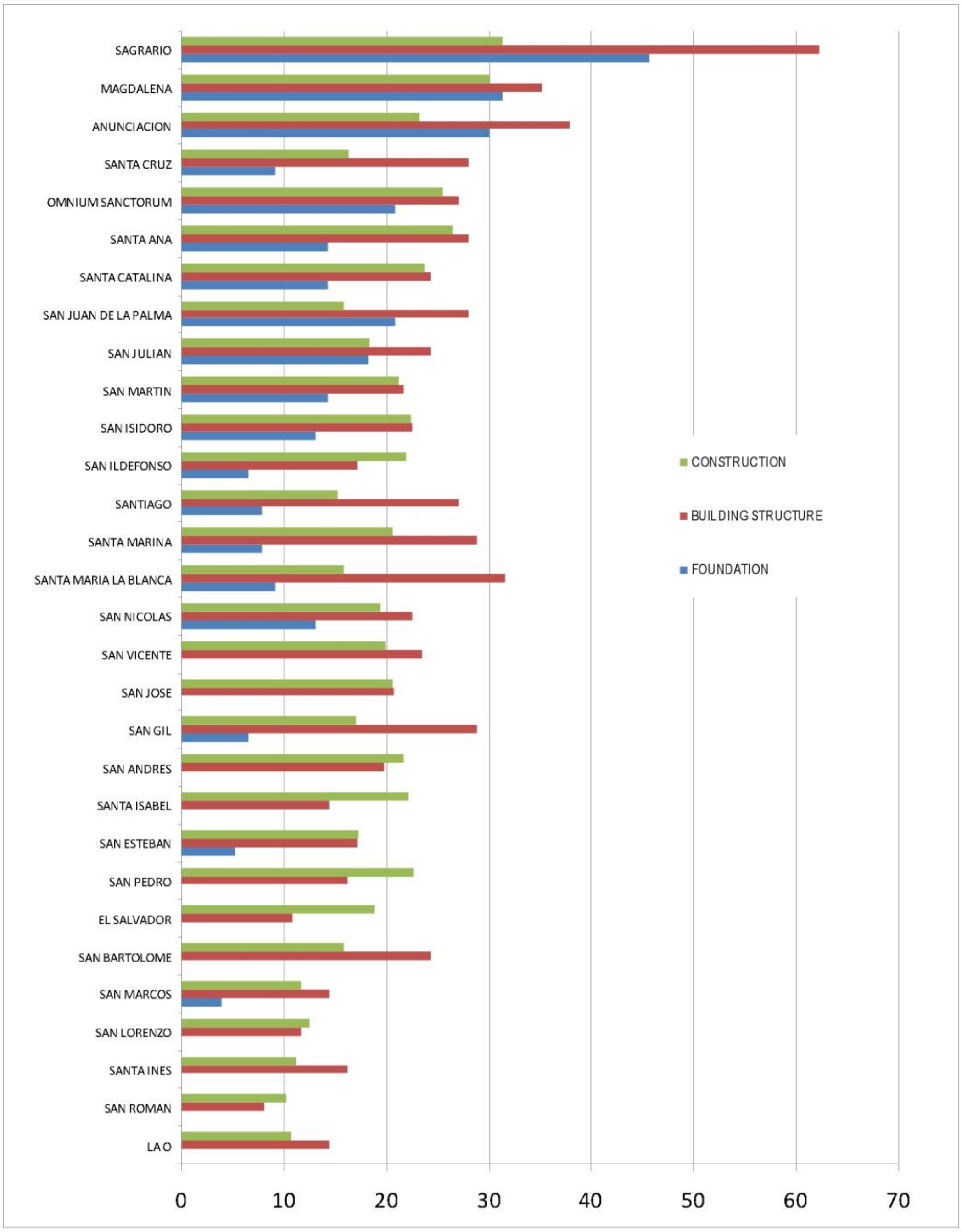


Figure 8. Influence of the factors related to structure system on the expanded vulnerability index for the 30 churches studied.

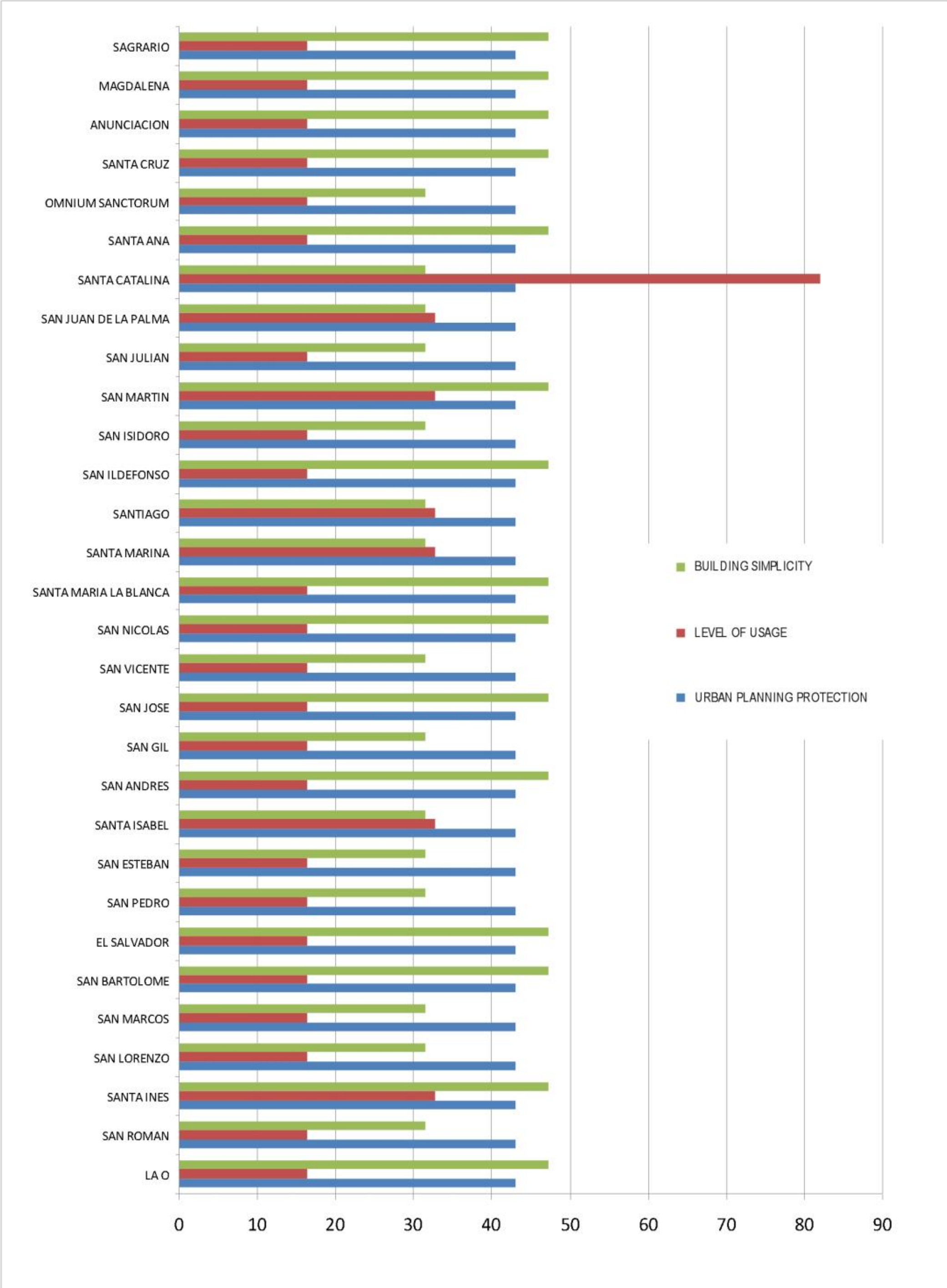


Figure 9. Influence of the factors related to building simplicity, level of usage and urban planning protection on the expanded vulnerability index for the 30 churches studied.

Table 1. Singular buildings chosen for study in the historic center of Seville and the district of Triana, periods of construction and architectural style. According to the Andalusian Building Heritage Database.

La Anunciación (ANUN) 16th Century (1565-1579)  Renaissance	La Magdalena (MAG) 17th-18th Century (1691-1709)  Baroque	Omnium Sanctorum (OS) 13th Century (1250-1399)  Gothic-Mudejar
San Esteban (SES) 14th-15th Century (1349-1414)  Gothic-Mudejar	San Gil (SGI) 14th Century (1300-1399)  Gothic-Mudejar	San Ildefonso (SIL) 18th-19th Century (1794-1841)  Neoclassical
San Isidoro (SISI) 14th Century (1345-1354) 	San José (SJO) 18th Century 	San Juan de la Palma (SJP) 15th Century (1400-1499) 

Gothic-Mudejar	Baroque	Gothic-Mudejar
San Julián (SJU) 14^{th}-15^{th} Century7 (1300-1407)  Gothic-Mudejar	San Lorenzo (SLO) 14^{th} Century (1300-1399)  Gothic-Mudejar	San Marcos (SMARC) 14^{th} Century (1345-1354)  Gothic-Mudejar
San Martín (SMTIN) 15^{th} Century (1400-1432)  Gothic-Mudejar	San Nicolás (SNI) 18^{th} Century (1758-1799)  Baroque	San Pedro (SPE) 15^{th} Century (1440-1499)  Gothic-Mudejar
Santa Ana (Triana) (STA) 13^{th}-14^{th} Century (1285-1350)  Gothic-Mudejar	Santa Catalina (STCA) 14^{th} Century (1350-1399)  Gothic-Mudejar	Santa Cruz (STCR) 17^{th}-18^{th} Century (1665-1728)  Baroque
Santa Inés (STIN) 14^{th} Century (1374)	Santa Isabel (STIS) 17^{th} Century (1602-1699)	Santa Marina (STMA) 14^{th} Century (1356)

 Gothic-Mudejar	 Baroque	 Gothic-Mudejar
Santa María la Blanca (STMB) 17th Century (1650-1665)  Baroque	San Román (SRO) 14th Century (1356-1399)  Gothic-Mudejar	San Vicente (SVI) 14th-16th Century (1300-1599).  Gothic-Mudejar
El Salvador (SALV) 17th-18th Century (1674-1712)  Baroque	San Andrés (SAND) 14th Century (1300-1399)  Gothic-Mudejar	Santiago (SANT) 14th-18th Century  Gothic-Mudejar
San Bartolomé (SBAR) 18th Century (1780-1796)  Neoclassical	Sagrario (SAG) 17th Century (1618-1622)  Baroque	La O (Triana) (O) 17th-18th Century (1697-1702)  Baroque

Table 2. Materials used in the buildings being studied. Note: R: materials introduced into the buildings after interventions.

				CONSTRUCTION SYSTEM	
TYPE OF MATERIALS	FOUNDATION	STRUCTURE		ROOF	COVERING
		Vertical	Horizontal		
STONE	X	X		X	X
BRICK	X	X			
METAL			R		
WOOD			X		
MORTAR					X
CERAMIC				X	
CONCRETE	R	R	R		

Table 3. Characterization of vulnerability matrix of Seville.

		MATERIAL			STRUCTURE				ANTHROPOGENIC FACTORS		
		PHYSICAL CHEMICAL CHARACTERISTICS	TEXTURE/ STRUCTURE	FIRE RESISTANCE	FOUNDATION	BUILDING STRUCTURE	CONSTRUCTION	BUILDING SIMPLICITY	VISUAL APPEARANCE	URBAN PLANNING PROTECTION	LEVEL OF USAGE
SOIL	GEOTECHNIQUE		frc,frag	frc,frag	frc,frag	frc,frag	frc,frag		frc,frag		
	UNDERGROUND WATER	e	am,ds,ar,ac,ad,ca,al,la,frc,fi,frag		frc,frag	ac,frc, frag	am,ds,ar,e,ac,ad,ca,al,la,frc,fi,frag		am,ds,ar,e,ac,ad,ca,al,la, frc,fi,frag		
WEATHER	WIND		er, ar, ad,ca,al				er, ar, ad,ca,al		er, ar, ad,ca,al		
	TEMPERATURE	e	am, ds, def, frc, fi,frag,la, ar,ds, pi			frc, fi, frag	am, ds, e, def, frc, fi, frag, la, ar, ds, pi		am, ds, e, def, frc, fi, frag, la, ar, ds, pi		
	RAIN	cc	ac, er, la, ad, ds, zl				ac, cc, la, ad, er, ds,zl		cc, ac, er, la, ad, ds, zl		
	DEW	e	ac, am, ds, frc, fi,frag, ad, er, ar				am, ds, e, frc, fi,frag, ac, er, ad, ar		am, ds, e, frc, fi,frag, ac, er, ad, ar		
NATURAL RISKS	EARTHQUAKES		pm, frc,frag	frc,frag	frc,frag	frc,frag	pm,frc, frag		pm,frc,frag		
ANTHROPIC ACTION	TOURIST PRESSURE		er				er		Er		
	USE/DISUSE		er, pm, ac, ex				er, pm, ac, ex		er, pm, ac, ex		
	FIRES		ac				ac		ac		
	BUILDING WORK	i	i	frc,fi, frag	frc,frag,i	frc,frag,i	frc,fi, frag, i		frc,fi,frag,i		
	WAR		pm				pm		pm		
	LOAD		def			def	def		Def		
POLLUTION	GASES	c					c		C		
	PARTICLES		d, pt				d, pt		d, pt		
BIOLOGICAL AGENTS		g, b	v		v	V	g, b, v		g, b, v		
MONUMENT SECURITY	VANDALISM (Graffiti, …)		ac, ex				ac, ex		ac, ex		
	ACCESIBILITY (Theft, loss of material…)		pm				pm		pm		

FEATURES INDUCED BY MATERIAL LOSS: **pm**: missing part; **la:** loss of painting area; **er:** erosion.
DISCOLORATION AND DEPOSIT: **ac:** colouration or discoloration, moist area and iron-rich patina; **zl:** soiling; **e:** efflorescence; **cc:** concretion; **pt:** patina; **d:** surface deposit; **c:** black crust; **g:** deposit of pigeon droppings
CRACK AND DEFORMATION: **def:** deformation **fi:** crack; **frc:** fracture; **frag**: fragmentation.
DETACHMENT: **ad:** differential erosion; **ar:** sanding, **ex:** scratching; **dc:** scaling; **ds:** detachment; **pi:** pitting; **al:** alveolization; **ca:** high alveolization; **am:** blistering
BIOLOGICAL COLONIZATION: **b:** biological colonization; **v:** plant.

Table 4. Classification of weathering forms.

Weathering form		**Name**	**Value**
FEATURES INDUCED BY MATERIAL LOSS	missing part	**pm**	**5**
	loss of painting area	**la**	**4**
	erosion	**er**	**3**
DISCOLORATION AND DEPOSIT	colouration or discoloration, / moist area / iron-rich patina	**ac**	**1/3/2**
	soiling	**zl**	**1**
	efflorescence	**e**	**3**
	concretion	**cc**	**3**
	patina	**pt**	**1**
	surface deposit **/** black crust	**d/c**	**1/2**
	deposit of pigeon droppings	**g**	**2**
CRACK AND DEFORMATION	deformation	**def**	**3**
	crack	**fi**	**2**
	fracture	**frc**	**5**
	fragmentation	**frag**	**10**
DETACHMENT	differential erosion	**ad**	**3**
	sanding	**ar**	**3**
	scratching	**ex**	**2**
	scaling	**dc**	**2**
	detachment	**ds**	**3**
	pitting	**pi**	**2**
	alveolization	**al**	**3**
	high alveolization	**ca**	**4**
	blistering	**am**	**2**
BIOLOGICAL COLONIZATION	biological colonization	**b**	**2**
	plant	**v**	**3**
OTHERS	building works	**i**	**3**

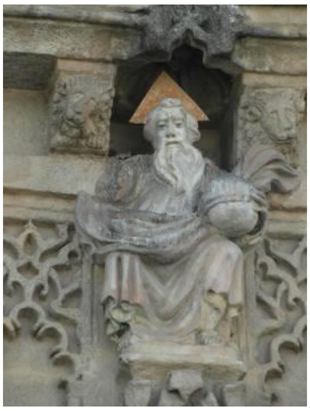
Table 5. Cutoff values of deterioration patterns.

	Low Frequency (1)	Medium Frequency (2)	High Frequency (3)
Very low damage (1)	1	2	3
Low damage (2)	2	3	4
Moderate damage (3)	3	4	5
High damage (4)	4	5	6
Very high damage (5)	5	6	7

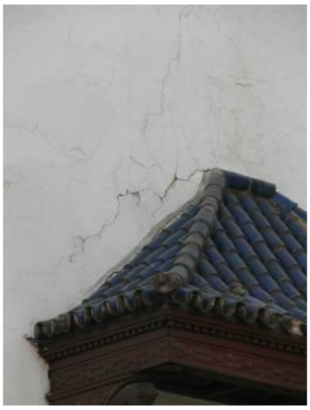
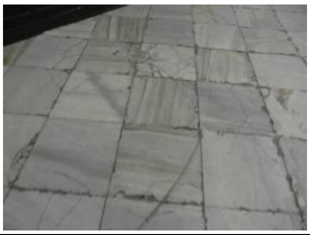
Table 6. Eight experts' opinions of vulnerability.

		EXP1	EXP2	EXP3	EXP4	EXP5	EXP6	EXP7	EXP8	MEAN	DEV.
Physical-chemical characteristics		70	75	80	40	90	30	50	60	62	21
Texture		70	40	30	50	70	10	30	40	43	21
Fire resistance		50	70	60	70	50	10	20	50	48	22
Foundation		30	70	100	50	90	20	50	100	64	31
Structure		60	70	100	70	70	40	80	100	74	20
Construction	Roof	80	90	80	70	90	100	90	100	88	10
	Covering	50	80	30	60	90	80	70	50	64	20
	Sewage	70	70	50	60	50	60	50	100	64	17
Building simplicity		30	50	50	80	50	70	70	100	63	22
Visual appearance		10	10	25	30	30	60	30	25	28	16
Urban planning protection		15	65	50	40	70	30	50	25	43	19
Level of usage		75	70	60	80	90	100	80	100	82	14

Table 7. Examples of Weathering forms founded in the churches (Seville).

FEATURES INDUCED BY MATERIAL LOSS	Missing part (pm)	Loss of painting area (la)
		
	Erosion (er)	
		
DISCOLORATION AND DEPOSIT	colouration or discoloration, / moist area / iron-rich patina (ac)	Soiling (zl)
		
	Deposit of pigeon droppings (g)	Concretion (cc)

		
	Patina (pt)	Surface deposit (d)
		
	Efflorescence (e)	Black crust (c)
		
CRACK AND	Crack (fi)	Fragmentation (frag)

DEFORMATION		
	Deformation (def)	Fracture (frc)
		
	differential erosion (ad)	Sanding (ar)
DETACHMENT		
	Scratching (ex)	Detachment (ds)

		
	Alveolization (al)	High alveolization (ca)
		
	Pitting (pi)	Blistering (am)
		
	biological colonization (b)	Plant (v)
BIOLOGICAL COLONIZATION		
OTHERS	building works (i)	

Table 8. Vulnerability degree for the 30 churches studied.

CHURCH	**Vulnerability**
LA O	Very Low
SAN ROMAN	Low
SANTA INES	Low
SAN LORENZO	Low
SAN MARCOS	Low
SAN BARTOLOME	Low
EL SALVADOR	Low
SAN PEDRO	Low
SAN ESTEBAN	Low
SANTA ISABEL	Low
SAN ANDRES	Low
SAN GIL	Low
SAN JOSE	Low
SAN VICENTE	Low
SAN NICOLAS	Moderate
SANTA MARIA LA BLANCA	Moderate
SANTA MARINA	Moderate
SANTIAGO	Moderate
SAN ILDEFONSO	Moderate
SAN ISIDORO	Moderate
SAN MARTIN	Moderate
SAN JULIAN	Moderate
SAN JUAN DE LA PALMA	Moderate
SANTA CATALINA	Moderate
SANTA ANA	Moderate
OMNIUM SANCTORUM	Moderate
SANTA CRUZ	Moderate
ANUNCIACION	Moderate
MAGDALENA	Moderate
SAGRARIO	High

Table 9. Matrix of priority based on level of vulnerability and level of uncertainty
Source: based on ICCROM–CCI–ICN (2007) for risk and uncertainty. [44]. it is highlighted in grey shadow the actions for the building in Seville according to DELPHI uncertainty.

Vulnerability					
Vulnerability degree	Very low (<10%)	Low (10-25%)	Moderate (25-50%)	High (50-75%)	Very high vulnerability (>75%)
Nº of Monuments	1	13	15	1	
Preventive/corrective Maintenance and Urban Policies					
Inspection	Yearly preventive surveillance and maintenance plan Cataloguing files and vulnerability calculation must be updated in case of changes or interventions, and it is advisable at least every three years or after a disaster such us floods, fires, earthquake, etc.				
Interventions	-	Underground water must be reduced in each building by on-site research studies and control of capillarity dampness		Intervention in short period (6-12 month)	Urgent Intervention (3 month)
Urban policies	Road traffic must be minimized in the historic town and near emblematic monuments				
Interventions and studies					
UNCERTAINTY – high	Requires research to ascertain that assessment is correct, but low priority.	Apply low cost mitigation; cost-benefit analysis of research to reduce uncertainty when highest risks have been dealt with.	High priority for research, cost-benefit analysis of the mitigation strategy is recommended.	High priority for research; short-term mitigation strategy is recommended; cost-benefit analysis of the mitigation strategy is recommended	Highest priority for research; short-term mitigation strategy will buy time until uncertainty is lower; cost-benefit analysis of the mitigation strategy is recommended.
UNCERTAINTY – moderate	Low magnitude of risk with moderate uncertainty is acceptable. Action is not necessary.	No direct action required but try to reduce the uncertainty. Cost-benefit analysis of mitigation versus research.	Risk mitigation prioritized by cost-benefit analysis of research and further risk analysis.	Risk mitigation prioritized by cost-benefit analysis of mitigation strategies, research and further risk analysis.	Second priority risk mitigation. Cost-benefit analysis of mitigation strategies and research is recommended.
UNCERTAINTY – low	Low magnitude of risk with low uncertainty is acceptable. No action.	Mitigate risk when highest risks have been dealt with, based on cost-benefit analysis of mitigation strategies.	Prioritize by cost-benefit analysis of mitigation strategies.	High priority for risk mitigation.	Highest priority for risk mitigation.