DOI: 10.7764/RIC.00034.21

Quality pathology assessment in historic buildings – case of the "basilica and convent of San Francisco"

Evaluación de patologías de calidad en estructuras históricas – caso "basílica y convento San Francisco"

M. Regalado[1*] http://orcid.org/0000-0002-6752-0196
E. Santa María * http://orcid.org/0000-0001-6789-4983
A. Gutiérrez * http://orcid.org/0000-0003-4038-0557
D. Suyón * http://orcid.org/0000-0001-6361-8658
J. Altamirano * http://orcid.org/0000-0001-8522-7092
L. Villanes * http://orcid.org/0000-0002-8633-7215
M. Rojas * http://orcid.org/0000-0002-5572-7720

* Universidad Nacional de Ingeniería, Lima, PERU

Fecha de Recepción: 21/05/2021
Fecha de Aceptación: 28/01/2022
Fecha de Publicación: 02/08/2022
PAG 292-303

Abstract

The purpose of the present paper is to set forth a methodology proposal for assessing quality pathologies (aesthetic and superficial) in historic buildings located in the city center of Lima (Peru), in order to identify the pathologies having the strongest impact on the overall quality of the structure, as well as their main causes. As a study case, the methodology is applied to the "Basilica and Convent of San Francisco", which allowed concluding that fissures are the pathologies that most affect the structure and earthquakes, and external vibrations are the main causes thereof

Keywords: *Pathologies; historic buildings; quality; visual inspection; Pareto chart*

Resumen

El presente artículo tiene como objetivo plantear una propuesta de metodología que permita evaluar las patologías de calidad (estéticas y superficiales) en estructuras históricas en el centro de la ciudad de Lima (Perú), de tal forma que puedan ser identificadas tanto las patologías que más repercuten en la calidad total de la estructura, como las causas principales de estas. Como caso de estudio, la metodología se aplica a la "Basílica y Convento de San Francisco", concluyendo que las patologías que afectan principalmente a la estructura son las fisuras, y que las principales causas son los sismos y las vibraciones externas.

Palabras clave: Patologías; edificios históricos; calidad; inspección visual; diagram de Pareto

[1] ***Corresponding author:***
Universidad Nacional de Ingeniería, Lima, PERU
E-mail: marck.regalado.e@uni.pe

DOI: 10.7764/RIC.00034.21

1. Introduction

A quality pathology is defined as the damage, harm or deterioration suffered by a structural element, which has a direct effect on its aesthetics and durability. The completion of the construction of a building requires that the client makes no observations; among others, the absence of quality pathologies. However, these pathologies can also arise over time, during its operational phase (Cortes and Perilla, 2017).

Cultural heritage serves as a symbol of a country's tradition, whose multiple historic buildings are part thereof. Hence, it is necessary to guarantee their continuity by rehabilitating them (Kutut et al., 2013), because they are part of the sustainable and cultural development of the country (Fernándes et al., 2016). Consequently, researchers are increasingly interested in the engineering problems concerning the conservation and restoration of the cultural heritage (Marinelli et al., 2019).

1.1 Problematic Reality

The historic buildings located in the city center of Lima (Peru), which emerged from the fusion of local and foreign knowledge, are a good example (Lombardi and Mountuori, 2018). Many of them evidence wear in the cladding, thus requiring constant repairs to maintain its aesthetic and cultural characteristics (Wang et al., 2020). However, this type of repairs is considered a complex activity in civil engineering, due to the lack of information about the original work (Marvila et al., 2020).

On the one hand, the structural wear in these buildings is caused by the presence of moisture, which can interact with the air pollution and cause limestone deterioration (Cavalagli et al., 2019). On the other hand, the chemical and mineralogical composition of their building materials, in addition to human actions during the occupation phase, also have a great impact on their deterioration (Rocha et al., 2018).

Likewise, since most of them were built based on masonry (such as adobe), without reinforcement (Leroy et al., 2005) or with low-strength mortars (Yao et al., 2021), their capacity to resist seismic forces is reduced; they can even collapse (Vargas, 2018). The problem gets worse given their complex geometry with curved structural elements, arches, domes, slim and massive elements (Pepi et al., 2021). Particularly, in old religious buildings, their classical configuration with wide-open spaces, external walls with no connection to perpendicular walls, and wooden roofs, increase their seismic vulnerability (Pauletta et al., 2018).

1.2 Research Question

Consequently, this research sets out to answer the following research question. How to control the quality pathologies in a historic building in the city of Lima, Peru?

1.3 State of the Art

With regard to the research subject, (Berenguel, 2018) studied the conservation of old buildings in the city of Lima, collecting data on cracks, microorganisms, deformations, detachment of materials in the buildings, as well as the presence of moisture. Then, he prepared a table with different types of pathologies, with the aim of establishing the damage they cause. The study concludes with recommendations for the conservation and repair of these buildings, with the purpose of extending their useful life.

(Mazer et al., 2016) studied the pathologies of 52 buildings in the city of Curitiba in Brazil, using visual inspections, photographic records and fissure depth measurements in basements, ground floor, rooftop, water tank and façade. The analyzed samples show the existence of corrosion in steel bars, wall fissures, leakage and paint detachment, most frequently in areas where the geographical orientation has a greater solar influence and/or high wind speeds.

(Lordsleem and Batista, 2017) analyzed the façade detachment in a 30-year-old residential building, due to pathological manifestations. Therefore, they applied a methodology including field data collection, as well as percussion and adhesion tests. The analysis evidenced the use of clay as a substitute of lime, which caused structural failures.

(Díaz, 2014) presents a method for analyzing pathologies in reinforced concrete buildings. He highlights the Delphi Method, which consists in an anonymous panel of experts addressing a specific matter, with the aim of finding a solution to a complex problem. The research included the participation of 25 experts, who were chosen according to selection criteria regarding their experience, publications, prestige in the subject area, and their interest in supporting the project. This enabled the definition of the study variables and the need for data in each one, through the experts' categorization using the rating scale of "Indispensable" (3), "Necessary" (2) and "Non-indispensable" (1).

(Reyes and Zaruma, 2017) used a method to identify the main methodologies in wood structures of structural buildings in Ecuador. They defined different structural elements (partitions, pillars, arches, beams, etc.), floors, staircases, divisions, woodwork and roof. In order to identify the pathology, a list of all potential pathologies was drawn (for ex., curvature of elements, warp, uneven floors, shear cracks in joints, white rot, etc.). The data collection emphasizes the use of different techniques, especially visual inspection and instrumentation. Moreover, the respective photographic records and an evaluation file card for each structure accompanied the entire data collection process.

DOI: 10.7764/RIC.00034.21

1.4 Theoretical Framework

Quality: Defined as the degree to which a set of inherent characteristics fulfills the requirements to satisfy a client. It represents the features that allow judging its value, where something is what it should be (and not something else). It allows defining its usefulness for the person using the product (Sanabria et al., 2014).

Cracks: Longitudinal openings affecting the entire depth of a building or structural element. The openings affecting just the surface or superficial finish are not considered cracks, but fissures. Cracks and fissures may appear on any structural element, due to factors such as settlings or lateral movements caused by earthquakes. However, they also arise from intrinsic characteristics of the materials, which are altered through overloads or vibrations caused by changes in the traffic or works with vibrators in nearby areas (Viviescas, 2010).

Moisture: It is considered one the most common and relevant physical damage on historic buildings. Moisture is produced when there is a high-water percentage, above that considered normal in building materials and/or elements, causing different physical variations. Moisture is considered a potential deterioration risk in the building element (Berenguel, 2018).

Earthquake: An earthquake is a sudden movement of the Earth, resulting from the vibrations coming from liberated energy that has accumulated during a certain time, mostly due to the interaction of tectonic plates (Dimililer et al., 2021). The main consequences of an earthquake are damages in the structural elements of a building, whose greatest impact are produced in the Peruvian coastline.

Pareto Chart: Tool that serves to detect or know the most relevant problems in a study. It specifies that 80% of the total results come from 20% of the elements (Tanabe, 2018). In order to obtain these results it is necessary to quantify the impact of each cause according to their different characteristics: frequency of occurrence, repair cost, effect on the client's satisfaction, etc.

2. Methodology

A quantitative research method was used, because the data used in the study are the types and quantities of pathologies identified in the field research. The research was explanatory, because it established a relationship between the pathologies and their potential causes, so as to identify those with the greatest impact (Hernández et al., 2014).

***Research Objective**:*
To identify the characteristics of the quality pathologies in a historic building in the city of Lima, Peru.

***Research Hypothesis**:*
Identifying the pathologies that most influence the quality in a structural building in the city of Lima (Peru), as well as their causes, will allow improving the corrective actions.

***Proposed Methodology**:*
Currently, visual inspection is the main and most important technique to identify the presence of damage and assess the structural health of historic buildings (Cavalagli et al., 2020); (Wang et al., 2019). Although mechanical destructive testing shows more accurate results regarding the current condition of the structure, they are very expensive and take much time, especially when they are applied to historic masonry buildings (Borri et al., 2018). Likewise, since they are part of the cultural heritage of a city, the idea is to make the minimum amount of modifications to the structure.
Since the purpose of quality is to satisfy a client, when considering the method to detect pathologies, the client corresponds to the owner of the historic building, who should be responsible for the respective maintenance after the corresponding assessment.
The proposed method, based solely on visual inspections, is explained below.

- *Data Collection Process*
  First, the types of pathologies that can be identified in the historic building are defined. The research sets out that the following rating scale will be used to differentiate the pathologies observed, considering only the "cracks" and "holes in the building":

  • Small: they are not detectable at first sight, you need to be standing in front of the façade in order to notice them.

  • Medium: they can be detected at first sight, but their size, shape and location do not give the observers the impression that there is considerable damage in the building.

  • Large: they can be detected at first sight and their size, shape and/or location give the observers the impression that there is considerable damage in the building.

  Then, the existence of each pathology is verified through photographic records in the field. The number of each pathology is recorded in a field journal. Finally, through expert judgment, all probable causes are defined for each pathology, with their respective impact level from 1 (minor impact) to 3 (strong impact).

- *Data analysis process*
  First, in order to establish, through expert judgment, which pathology has the strongest impact, each one is assigned a severity rate from 1 (mildly severe) to 5 (highly severe), in relation to its influence on the overall quality of the building. A Pareto chart is made by combining the values with their respective quantities (Tanabe, 2018), thus obtaining the pathology with the strongest impact.
  In order to obtain the cause having the strongest impact, the effects on each pathology are combined with the number and severity rate of the pathology. In this way, a Pareto chart is made to obtain the cause having the strongest impact.

- *Flowchart*
  Below, (Figure 1) shows a flowchart of the proposed methodology.

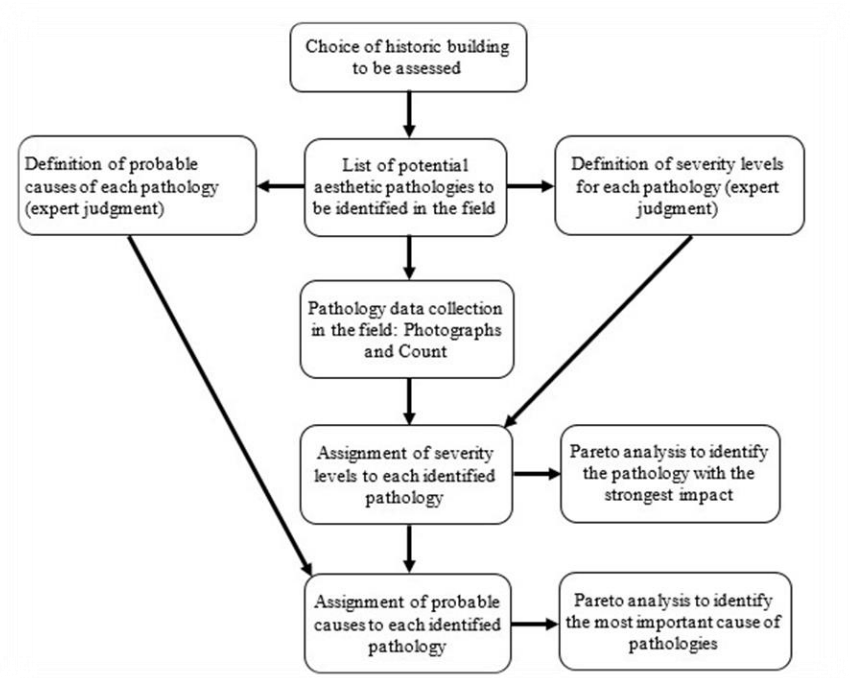

Figure 1. *Flowchart of proposed methodology*
Source: Self-prepared

Research Population and Sample: The population covered in this research includes all the historic buildings in the city center of Lima, Peru. The research sample was the Basilica and Convent of San Francisco (Alcántara, 2018), and the objective of this choice was to study a pilot building to apply the proposed methodology. This structure is also representative, since it features age characteristics similar to the rest of the research population. Additionally, it was necessary to choose a public building, because the pathologies were closely photographed and observed, something that would have been restricted in private buildings.

3. Results

3.1 Data Collection

Number of Pathologies: (Table 1) below shows the types and quantities of the pathologies collected in the field. As explained earlier in relation to "cracks" and "holes in the building", the rating scale of small, medium and large is used, according to the visibility of the pathology and the observers' impression regarding the safety of the structure.

DOI: 10.7764/RIC.00034.21

Table 1. Type of pathology and quantity

Type of Pathology	Quantity			
	Total	Small	Medium	Large
Cracks	33	18	10	5
Holes in the building	12	7	3	2
Worn finish	4			
Hanging cables	4			
Unusable light bulbs	4			
Exposed pipes	1			

Source: Self-prepared

(Figure 2), (Figure 3) and (Figure 4) show images of field-collected data. It should be noted that the data collection process was limited to the area of the façade that is visible for any person walking by the area of the building. In other words, the areas of the façade that are not visible or have restricted access (by order of the building's owners), were not included in the study. Nevertheless, if these areas have viewing limitations, they would not affect the building's aesthetics, which would correspond solely to the areas that can be detected by any passerby.

Figure 2. *Crack detection (medium)*
Source: Self-prepared Source: Self-prepared

DOI: 10.7764/RIC.00034.21

Figure 3. *Hole in the project (large)*
Source: Self-prepared

Figure 4. *Exposed pipes*
Source: Self-prepared

Identification of Probable Cause of Pathologies: *(Table 2) shows probable causes for each type of pathology, which have been validated by expert judgment of five collegiate civil engineers with a long professional experience on construction projects and acquired knowledge on causes of common pathologies. Once again, it should be highlighted that pathologies refer to the aesthetics of the historic building only. However, the cause may be related to its structural behavior and that is why it was decided to rely on the advice of civil engineers.*

DOI: 10.7764/RIC.00034.21

Table 2. *Probable causes according to the type of pathology*

Type of Pathology	Probable Cause	Description
Cracks	Ground settling	Settlings can produce cracks in the structure.
	Earthquakes	Earthquakes produce vibrations in the structure, thereby generating cracks.
	Poor building process	Stripping too soon, when concrete has not yet reached its maximum strength, causes greater deformations and therefore cracking.
Worn Finish	Moisture	As time goes by and without proper maintenance, moisture deteriorates the material.
	Pigeon excrement	As time passes, pigeon excrement deteriorates the material. It produces more damage than moisture due to its organic components.
Holes in the Building	Poor building process	Stripping too soon, when concrete has not yet reached its maximum strength, causes greater deformations. In critical cases, this will produce openings in the structure.
	Earthquakes	They produce vibrations in the structure, which can generate openings in areas with lower structural strength.
	External vibrations	The vibrations of machines working on the exterior can cause vibrations in the structure, which can generate openings.
Hanging Cables	Lack of maintenance	The façade is subject to wear due to environmental factors and, if no regular maintenance is carried out, cables will start to be exposed and will end up hanging on the structure.
	Pigeon pecking	Pigeons constantly wear the structure physically.
Unusable Light Bulbs	Lack of maintenance	As time passes, the lack of maintenance makes light bulbs unusable. Many of them are never changed.
	Pigeon pecking	Pigeons destroy the light bulbs with their pecking. Many of them are never changed.
Exposed Pipes	External vibrations	The ground movement, caused by earthquakes or machineries, causes cracking in the pavement, thus exposing the pipes.
	Pavement quality	A poor-quality pavement is rapidly worn out and causes pipe exposure.

An impact level is assigned to each probable cause, which ranges from (minor impact) to 3 (strong impact), as observed in (Table 3) below.

Table 3. *Impact level according to the pathology cause*

Type of Pathology	Probable Cause of the Pathology (Impact on Pathology)		
Cracks	Ground settling (2)	Earthquakes (3)	Poor building process (2)
Worn Finish	Moisture (2)	Pigeon excrement (3)	
Holes in the Building	Poor building process (2)	Earthquakes (1)	External vibrations (3)
Hanging Cables	Lack of maintenance (1)	Pigeon pecking (3)	
Unusable Light Bulbs	Lack of maintenance (3)	Pigeon pecking (1)	
Exposed Pipes	External vibrations (3)	Pavement quality (2)	

Source: Self-prepared

3.2 Pathology with the Strongest Impact

First, the severity rate for each pathology is assigned based on their impact on the overall quality of the structure, and the values range from 1 (mildly severe) to 5 (highly severe). Then, these values are multiplied by the quantity of each pathology according to (Table 1), thereby obtaining an impact value. The results in (Table 4) are presented in descending order according to the resulting impact value, which is also converted to a percentage scale. Next, both impact results are accumulated to identify the point where the Pareto principle is fulfilled.

Table 4. *Pathology Analysis*

Type of Pathology	Severity	Quantity	Impact	Impact %	Accumulated	Accumulated %
Cracks	4	33	132	59.7%	132	59.7%
Holes in the Building	5	12	60	27.1%	192	86.9%
Worn Finish	3	4	12	5.4%	204	92.3%
Hanging Cables	2	4	8	3.6%	212	95.9%
Unusable Light Bulbs	2	4	8	3.6%	220	99.5%
Exposed Pipes	1	1	1	0.5%	221	100%
			221	100%		

Source: Self-prepared

DOI: 10.7764/RIC.00034.21

(Figure 5) shows the Pareto chart based on the previous information. It is possible to observe that cracks are the most common pathologies in the historic building (59.7%).

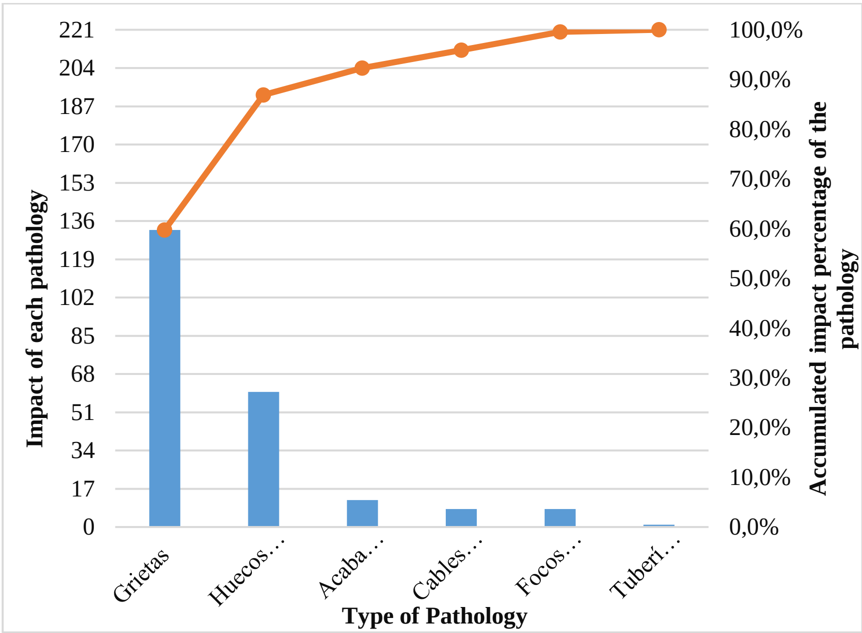

Figure 5. *Pareto Chart - Pathologies*
Source: Self-prepared

3.3 Cause with the Strongest Impact

Below, the probable causes, with their respective impact indexes (according to (Table 3)), are ordered according to each pathology, quantity and severity rate previously used.

Regarding (Table 5), the impact of each cause has been multiplied in each cell, with the respective quantity and severity rate of the corresponding pathology. The resulting values are the impacts that each cause has on every pathology. These values are added, thus obtaining the total impact of each cause, which is then converted into a percentage scale.

The following initials were used for reference of probable causes:
- *Ground settling (GS)*
- *Earthquakes (EQ)*
- *Poor building process (PP)*
- *Moisture (MO)*
- *Pigeon excrement (PE)*
- *External vibrations (EV)*
- *Lack of maintenance (LM)*
- *Pigeon pecking (PP)*
- *Pavement quality (PQ)*

DOI: 10.7764/RIC.00034.21

***Table 5.** Impact of causes per each pathology*

Pathology			Probable Cause (Impact per Pathology)								
Type of Pathology	Quantity	Severity	GS	EQ	PP	MO	PE	EV	LM	PP	PQ
Cracks	33	4	264	396	264	0	0	0	0	0	0
Worn Finish	12	5	0	0	0	120	180	0	0	180	0
Holes in the Building	4	3	0	12	24	0	0	36	0	0	0
Hanging Cables	4	2	0	0	0	0	0	0	8	24	0
Unusable Light Bulbs	4	2	0	0	0	0	0	0	24	8	0
Exposed Pipes	1	1	0	0	0	0	0	3	0	0	2
Cause Total Impact			264	408	288	120	180	39	32	212	2
Percent Impact (%)			17.1%	26.4%	18.6%	7.8%	11.7%	2.5%	2.1%	13.7%	0.1%

Source: Self-prepared

In (Figure 6), the Pareto chart includes the previous results, which evidence that 26.41% of the quality problems are associated with pathologies caused by earthquakes. Therefore, this is the cause that will have the strongest impact on the quality pathologies of the historic building.

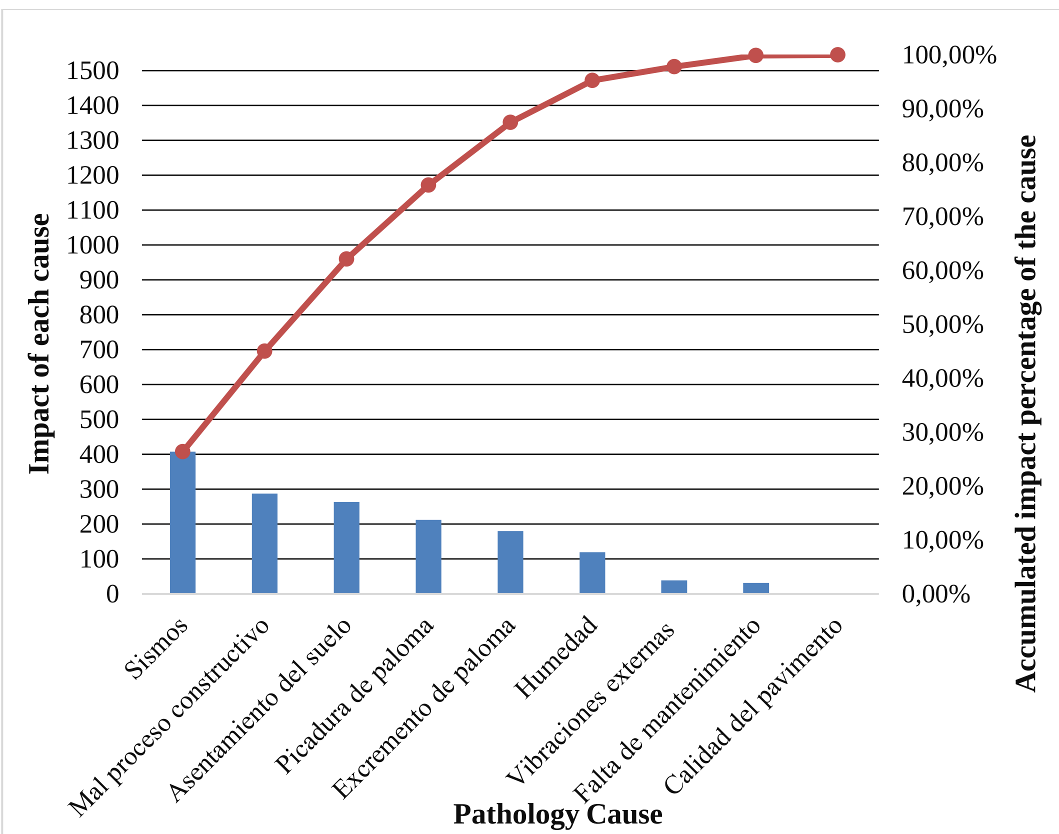

Figure 6. Pareto chart - Causes
Source: Self-prepared

DOI: 10.7764/RIC.00034.21

4. Discussion

• The analysis covered only the exterior of the building and not the interior, because the national Government has suspended the access to these religious buildings, as a measure to control the pandemics caused by the SARS-CoV-2 virus. The analysis of the façade was not fully completed, because the upper part of the building was not possible to assess visually; therefore, more sophisticated instruments are required (such as drones).

• In relation to cracks and fissures, they have been considered jointly as cracks only; they have not been differentiated by depth, because the necessary equipment was not used, as the proposed method is purely visual.

5. Conclusions

• Earthquakes are the cause with the strongest impact (26.41%) on the quality pathologies of the Basilica and Convent of San Francisco of Lima and, therefore, the hypothesis set forth is verified.
• Cracks are the pathologies with the strongest impact (59.7%) on the overall quality of the Basilica and Convent of San Francisco of Lima and, thus, the hypothesis set forth is verified.
• Based on the above information, the corrective measure to repair the cracks on the building façade would allow, in the short term, to improve the overall quality by 59.7%. On the other hand, in the long term, the preventive measure of reinforcing the structure to prevent the pathologies generated mostly by earthquakes would reduce the causes by 26.41% minimum. Consequently, the hypothesis set forth is validated.

6. References

Alcántara G., R. M. (2018). Documentación previa en las intervenciones de patrimonio edificado, análisis del caso: Iglesia de San Francisco de Lima (1978-1990). Devenir - Revista de estudios sobre patrimonio edificado, 5(9), 29-50. https://doi.org/10.21754/devenir.v5i9.199.

Berenguel P., A. E. (2018). Patología de la edificación patrimonial en el centro histórico de Lima. Humedades, causas y consecuencias. Devenir - Revista de estudios sobre patrimonio edificado, 1(1), 93-108. https://doi.org/10.21754/devenir.v1i1.239.

Borri, A.; Corradi, M.; De Maria, A.; Sisti, R. (2018). Calibration of a visual method for the analysis of the mechanical properties of historic masonry. Procedia Structural Integrity, 11, 418-427. https://doi.org/10.1016/j.prostr.2018.11.054.

Cavalagli, N.; Gioffrè, M.; Grassi, S.; Gusella, V.; Pepi, C.; Volpi, G.M. (2020). On the accuracy of UAV photogrammetric survey for the evaluation of historic masonry structural damages. Procedia Structural Integrity, 29, 165-174. https://doi.org/10.1016/j.prostr.2020.11.153.

Cavalagli, N.; Kita A.; Castaldo V.L.; Pisello A. L.; Ubertini F. (2019). Hierarchical environmental risk mapping of material degradation in historic masonry buildings: An integrated approach considering climate change and structural damage. Construction and Building Materials, 215, 998-1014. https://doi.org/10.1016/j.conbuildmat.2019.04.204.

Cortes H., B.; Perilla M., K. (2017). Identificación de patologías estructurales en edificaciones indispensables del municipio de Santa Rosa de Cabal (tesis de pregrado). Pereira: Universidad Libre seccional Pereira.

Díaz Barreiro, P. (2014). Protocolo para los Estudios de Patología de la Construcción en Edificaciones de Concreto Reforzado en Colombia [Trabajo de grado, Pontificia Universidad Javeriana]. https://repository.javeriana.edu.co/bitstream/handle/10554/12694/DiazBarreiroPatricia2014.pdf;jsessionid=F44EF584359C970D5D585FE09D6BA066?sequence=1

Dimililer, K., Dindar, H.; Al-Turjman, F. (2021). Deep learning, machine learning and internet of things in geophysical engineering applications: An overview. Microprocessors and Microsystems, 80, 103613. https://doi.org/10.1016/j.micpro.2020.103613

Fernandes, C.; de Brito, J.; Oliveira, C. (2016). Architectural integration of ETICS in building rehabilitation. Journal of Building Engineering, 5, 178-184. https://doi.org/10.1016/j.jobe.2015.12.005.

Hernández, R.; Fernández, C.; Baptista, P. (2014). Metodología de la Investigación. Sexta Edición. México D.F.: Mc Graw Hill Education.

Kutut, V.; Kazimieras Z.; Lazauskas, M. (2013). Assessment of Priority Options for Preservation of Historic City Centre Buildings using MCDM (ARAS). Procedia Engineering, 57, 657-661. https://doi.org/10.1016/j.proeng.2013.04.083.

Leroy, E.; Kimbro, E.; Ginell, W. (2005). Guías de planeamiento e ingeniería para la estabilización sismorresistente de estructuras históricas de adobe. California: The Getty Conservation Institute.

Lombardi, A.; Montouri, P. (2018). El centro histórico de Lima entre conservación y uso inadecuado del patrimonio histórico arquitectónico 'menor'. Devenir - Revista de estudios sobre patrimonio edificado, 1 (2), 97-109. https://doi.org/10.21754/devenir.v1i2.253.

Lordsleem, A. C.; Batista, H. (2017). Building facade cladding detachment: A case study. Revista ALCONPAT, 7(2), 148-159. http://dx.doi.org/10.21041/ra.v7i2.126.

Marinelli, A.; Santa, S.; Spiliopoulos, A.; Dasiou, M. (2019). Optimizing strengthening interventions on historic masonry walls: an experimental study. Procedia Structural Integrity, 18, 245-254. https://doi.org/10.1016/j.prostr.2019.08.160.

Marvila, M.; Azevedo, A.; Barroso, L.; Barbosa, M.; de Brito, J. (2020). Gypsum plaster using rock waste: A proposal to repair the renderings of historical buildings in Brazil. Construction and Building Materials, 250, 118786. https://doi.org/10.1016/j.conbuildmat.2020.118786.

Mazer, W.; Silva, L.; Lucas, E.; Santos, F. (2016). Evaluación de manifestaciones patológicas en edificios en función de la orientación geográfica. Revista ALCONPAT, 6(2), 145-156. https://doi.org/10.21041/ra.v6i2.135.

Pauletta, M.; Di Luca, D.; Russo, E.; Fumo, C. (2018). Seismic rehabilitation of cultural heritage masonry buildings with unbonded fiber reinforced elastomeric isolators (U-FREIs) - A case of study. Journal of Cultural Heritage, 32, 84-97. https://doi.org/10.1016/j.culher.2017.09.015.

Pepi, C.; Cavalagli, N.; Gusella, V.; Gioffrè, M. (2021). An integrated approach for the numerical modeling of severely damaged historic structures: Application to a masonry bridge. Advances in Engineering Software, 151, 102935. https://doi.org/10.1016/j.advengsoft.2020.102935.

Reyes Ochoa, J. A.; Zaruma Mochas, L. A. (2017). Identificación y solución de lasprincipales patologías presentes en estructuras de madera de edificaciones patrimoniales, localizadas en el Centro Histórico de Cuenca – Ecuador [Trabajo de titulación, Universidad de Cuenca]. http://dspace.ucuenca.edu.ec/handle/123456789/28646.

Rocha, E.; Macedo, J.; Correia, P.; Monteiro, E. (2018). Adaptation of a damage map to historical buildings with pathological problems: Case study at the Church of Carmo in Olinda, Pernambuco. Revista ALCONPAT, 8(1), 51-63. http://dx.doi.org/10.21041/ra.v8i1.198.

Sanabria Rangel, P. E., Romero Camargo, V. C.; Flórez Lizcano, C. I. (2014). El concepto de calidad en las organizaciones: una aproximación desde la complejidad. Universidad; Empresa, 16(27), 157-205. http://dx.doi.org/10.12804/rev.univ.empresa.27.2014.06.

Tanabe, K. (2018). Pareto's 80/20 rule and the Gaussian distribution. Physica A, 510, 635-640. https://doi.org/10.1016/j.physa.2018.07.023

Vargas, H. (2018). Reparación de grietas en construcciones históricas de tierra en áreas sísmicas Parte V: "Desarrollo de método de diseño de refuerzo sísmico y comprobación experimental" (tesis de pregrado). Lima: Pontificia Universidad Católica del Perú.

Viviescas, J. C. (2010). Grietas en construcciones ocasionadas por problemas geotécnicos (tesis de pregrado). Medellín: Universidad EATIF.

Wang, N.; Zhao, X.; Zhao, P.; Zhang, Y.; Zou, Z.; Ou, J. (2019). Automatic damage detection of historic masonry buildings based on mobile deep learning. Automation in Construction, 103, 53-66. https://doi.org/10.1016/j.autcon.2019.03.003.

Wang, Q.; Yang, C.; Lu, J.; Wu, F.; Xu, R. (2020). Analysis of preservation priority of historic buildings along the subway based on matter-element model. Journal of Cultural Heritage, 45, 291-302. https://doi.org/10.1016/j.culher.2020.03.003.

Yao, X.; Guo, Z.; Humayun B.; Huang, Q. (2021). Innovative seismic strengthening of historic masonry walls using polymer mortar and steel strips. Engineering Structures, 228, 111507 https://doi.org/10.1016/j.engstruct.2020.111507.