Aplicación del método Delphi en el ajuste y validación de herramientas para evaluaciones de edificios

Application of the Delphi method in the adjustment and validation of tools for building evaluations

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Abstract

The correct way to intervene damage to a building is from the study of the characteristics of the lesions and causes that gave rise to their appearance. For this, it is convenient to have tools in the collection of information, data processing and results analysis. In the industry branch, aeronautics, transport, among others, operational reliability has been developed as a philosophy to improve processes. Within this there are various tools such as the criticality analysis, the method of the impacts and the technique of Pareto, which allow to determine the criticality of a relationship, element or system. For not having evidence that these have been used for constructive evaluations, it was necessary to adjust the terminology, the parameters and their weights. For the validation of the proposed adjustments, the Delphi method where 20 specialists participated were used. In the critical analysis, the levels and indexes of frequency, impact and detectability were established, as well as the fields, attributes and importance for each of them, which will also be used in the Pareto technique for the analysis of the consequences. In the impact method, 16 parameters and their categories for the technical, functional and economic evaluation of the building were defined. These tools allow the evaluation of the systems of a building in an integral way, since the effects of constructive damages are considered functional, sanitary, environmental and economic fields.

Keywords: Building Evaluation Tools, Adjust and Validation of Tools, Delphi Method

Resumen

La forma correcta de intervenir los daños en una edificación es a partir del estudio de las características de las lesiones y de las causas que dieron lugar a su aparición. Para ello, es conveniente contar con herramientas en la recopilación de información, el procesamiento de datos y el análisis de resultados. En la rama de la industria, la aeronáutica, el transporte, entre otros, se ha desarrollado la confiabilidad operacional como una filosofía de mejora de los procesos. Dentro de esta existen diversas herramientas como el análisis de criticidad, el método de los impactos y la técnica de Pareto, que permiten determinar la criticidad de un deterioro, elemento o sistema. Por no

contar con evidencias de que estas hayan sido empleadas para evaluaciones constructivas, fue necesario ajustar la terminología, los parámetros y sus ponderaciones. Para la validación de los ajustes propuestos se empleó el método Delphi donde participaron 20 especialistas. En el análisis de criticidad quedaron establecidos los niveles e índices de frecuencia, impacto y detectabilidad, así como los campos, atributos y niveles de importancia para cada uno de ellos, que además, serán empleados en la técnica de Pareto para el análisis de las consecuencias. En el método de los impactos se definieron 16 parámetros y sus categorías para la evaluación técnica, funcional y económica de la edificación. Estas herramientas permiten la evaluación de los sistemas de una edificación de forma integral, pues se consideran las afectaciones de los daños constructivos sobre campos funcionales, sanitarios, ambientales y económicos.

Palabras clave: Herramientas de evaluación de edificaciones, ajuste y validación de herramientas, método Delphi

1. Introduction

The appearance of lesions in constructive components of a building may be due to a large number of causes; these can be: aging of the materials, errors in the project stages, exploitation of the property or absence of management; in all cases, constructive lesions can be eradicated or at least minimized, if proper maintenance is carried out, which is defined as: service that groups a series of activities whose execution allows to achieve a greater degree of reliability in the equipment, machines, civil constructions and facilities or as the action of preserving, correcting or preserving the functions and concentrations of availability, safety and efficiency of fixed assets during their life cycle [1].

Constructive maintenance, generally, is summarized in correcting those injuries that appear in the building, being in many cases, late actions that hide the true causes of failures, which evolve to a third generation, causing great functional effects or structural. This generally derives in high expenses for repairs. The fundamental cause of this problem is the lack of qualified personnel for the inspection, detection and evaluation of the lesions that appear in the building.

The first step, to undertake a correct intervention, is to make an adequate diagnosis and evaluation of the building, where the total injury is identified in each building construction system, as well as the analysis of the causes that continued to it, in addition, the recognition of the possible consequences associated with this deterioration is of the utmost importance, especially for cases where treatment is not an immediate action. In buildings it is necessary to count or hire trained staff to apply evaluation techniques that guarantee the correct proceeding in the diagnosis and intervention of the building, with the solutions that best adapt to the conditions of the building; which would lead to good management, from the economic point of view, within a convenient period to avoid the excessive pathological evolution of existing injuries.

Operational reliability is the synergistic action of equipment, human resource and the technological process, to ensure that a complex technical system fulfills the functions required in a certain time and operational context [1] and, despite containing a series of continuous improvement processes, which systematically incorporates, advanced diagnostic tools, analysis methodologies and new technologies, to optimize the management, planning, execution and maintenance control, there is no evidence that it has been used in the evaluation of built heritage. These methods are generally used in complex systems associated with industries, aeronautics, automotive parks, car system, among others [2-4].

With the objective of carrying out an evaluation of the components of a building, taking into consideration the influence of constructive damages on other elements of the building, the environment and the user himself, tools of operational reliability are selected, validating the feasibility of its application in this type of evaluations through the Delphi expert method.

2. Materials and methods

There are multiple tools that are served operational reliability in order to formulate strategic plans to achieve excellence in maintenance activities, including: criticality analysis, analysis of modes and fault effects, cause-root analysis, risk-based inspection, cost-risk analysis and analysis of the life cycle, to which other tools such as Pareto technique and the impact method are added. From these tools the methods were selected: criticality analysis, Pareto technique and impact method, because through these you can determine the level of criticality of the damage. However, it will be necessary to adjust these tools in terms of terminology, parameters, attributes and categories defined in literature for other applications, mainly in the field of mechanical engineering, maintenance engineering or industry areas.

2.1 Critical analysis

The implementation of the critical analysis method can be carried out in a practical way, depending on the level of detail of the subsystem analysis according to the expected benefits, through qualitative and/or quantitative techniques in which the prioritization and determination of the level of criticality based on the impact associated with the occurrence of various damages [5], allowing you to optimize the decision-making process, resource allocation and strategies, which include where efforts should be concentrated in maintenance areas and thus obtain the best results.

In this case, the analysis is carried out using tables that group and classify the deteriorations depending on the frequency of occurrence, the impact and also the difficulty in detecting the injuries. For the ranking, a weight will be assigned to the parameters to be analyzed in each deterioration from the standard tables, defining the number of times this appears, another weight according to the severity of its impact and finally a value, depending on the difficulty for detection [6]. The mathematical equation selected to find the criticality index (C) takes into account the frequency with which a fault multiplied by the magnitude of the consequence and the difficulty for its detection and study occurs, as shown in below [7]:

$$C = \text{Consequence} * \text{Probability of occurrence} * \text{Detectability} \tag{1}$$

2.2 Pareto technique

The Pareto principle presents the concept that, in most situations, 80% of the consequences are the result of 20% of the causes [8]. This can be very useful for treating non-conformities, identifying improvement points and defining what action plans should be attacked first in terms of priority [8] and according to its concept, it is more useful to identify which or what are the main causes in the investigated probing, and thus, to reach the planning of activities with the purpose of mitigating those potential causes that affect the provision of the service and achieve the improvement of this [9].

When this technique applies to reliability, it is based on a statistical analysis of the frequencies that present the failures identified in a system, which obtained the classification in A, B or C. Class A associated with the failures of the highest level of criticality, class B to those of medium level and class C, to those of low level of criticality, from which the importance relationship of classes is established [10].

2.3 Impact method

The method analyzes various technical-economic and functional parameters that, depending on its importance, each one is categorized into A, B or C, with the observation, that each parameter is valued individually without thinking about the influence on others, as if he only decided the classification. In the end they are added by category and decides what is the category that corresponds to the element or system [11].

2.4 Aplicación del método Delphi

The use of operational reliability tools for the constructive technical evaluation of buildings is a novel area, but of successful research, since it is feasible to determine the level of criticality that each deterioration detected in the building presents. This indicator is quantifiable and therefore establishes hierarchy in the lesions, which allows the analysis of each system from the frequency, impact and detectability of failures. There was no evidence of the use of criticality analysis, the Pareto technique and the impact method for the technical evaluation of built heritage, its use stands out in the evaluation of processes, machinery, technologies and others, mainly in the area of the industry. For this reason, it is necessary to adjust these tools to the construction area in terms of: levels of criticality, parameters, attributes and weighting of these. Presenting this group of tools to criteria of experts in the subject of building evaluation, is essential for the validation of these novel methods in the area and their future application in the assessment of the arrests existing in the buildings.

For the adaptation of the tools, the Delphi method was selected for being an iterative process, which allows adapting the adjustments taking into account the criteria of the experts; panel members do not interact, so there is no possibility of influencing the responses of others [12]; It allows feedback, fundamental aspect for the adjustment process and; The results are valid once the consensus is achieved among the members of the panel [13]. Specialists were selected with vast experience in the construction sector, both civil engineers and architects, willing to participate voluntarily in the investigation. As premises, it was, to have a representative sample of specialists who perform different professional roles within the sector, but with knowledge about the theme to validate. The panel was conducted by 20 experts and its characterization is presented in Table 1.

Table 1. Summary of the characterization of the experts surveyed

Experience (years)	Scientific Degree		Specialty		Level of competence		
Average	Master	PhD	Architecture	Civil Engineering	High	Medium	Low
29	3	13	5	15	10	8	2

Once the expert competence coefficient was determined, it was decided that, the specialists who had to continue in the study were the ones who had a medium or high level of competition, interrupting the process for those of low level. For all the above, the sample is reduced to 18 experts, 10 high competition and 31 years of average experience and eight of medium competition with an average of 26 years of experience.

The adjustment proposals were presented to experts in the form of a questionnaire where they could select the option that, in their opinion, better adapted to the evaluation of buildings, with the freedom to add, not accept and offer criteria in this regard.

Adjustment proposal for the critical analysis. This technique is easy to handle and understanding, in which relative ranges are established to represent the probabilities and/or frequencies of event

occurrence and their impacts or consequences, for which it is due make the estimation of frequency and impact scores. The values   can be defined from similar studies that appear in the literature or through interviews and/or surveys of the personnel specialized in the subject, where they select according to their criteria and knowledge, the value of the score that will be assigned to each indicator, based on the characteristics of your field of action. Parameter or indication scores can be as diverse as critical analysis models exist, as each evaluation team can elaborate and validate their own methodology.

For the adaptation of the index and frequency level, five intervals combination are proposed according to the relative frequency that represents the occurrence of constructive lesions, where experts must select the combination, they consider best to adjust to this type of evaluations (Table 2).

Table 2. Adjustment proposal for the frequency of occurrence

Frequency of occurrence	Index of frequency	Porcentage of occurrence (%)					Description
		1	2	3	4	5	
High	3	>50	>60	>70	>80	>90	% times that a deterioration appears with respect to the total injuries identified in the analyzed system
Medium	2	5- 50	15-60	25- 70	35 -80	40- 90	
Low	1	<5	<15	< 25	<35	<40	
Selection							

The impact generated by an injury is given by the consequences caused by the existence of this in a given element or system, this can be evaluated from the fields or areas affected by a deterioration, establishing values   that depend on its importance. The first to define in determining the impact index, are the fields that can be affected by any injury that appears in the component systems of the building. Below is the definition of each of the fields defined for this investigation.

Structure. This field will be taken into account when the identified lesion directly affects the component systems of the building, whether structural or not.

Functionality. It will be taken into account if the deterioration affects any of the processes or flows that are an indispensable part of the functionality of the building, interrupting or hindering their own activities according to their mission.

Health and safety. It is determined for injuries that affect the health and/or safety of users or visitors of the building.

Environment. It will be taken into account when the lesion directly affects the components and/or the space in which the life of the organisms and their interaction develops.

Economic affectation. When production, services, economic activity or other independent systems are affected.

Comfort. This field is directly related to the welfare and comfort of the person in their environment, which can be their work center, their home or the place that it usually frequents.

Aesthetics. It will be taken into account when deterioration affects architectural harmony.

Value. What represents a set of beliefs, languages, customs, traditions and relationships that identify a society or group of people.

Quality. Product adaptation and/or service to consumer needs and requirements. Quality of compression. This basically refers to the degree to which the product or service meets established quality standards or norms.

Availability. It is associated with the necessary resources for the restoration of the area affected by the lesion.

Repair cost. Assessment of the repair of the affected element or system.

To base the possible affectation in each of the fields, attributes are established, they offer the possibility of limiting the affectation within the affected field, however, for this it will be necessary to define the importance that each of these parameters acquires within the valuation of the impact, so experts are presented Table 3. The specialists must select those fields and attributes that are necessary to analyze and their level of importance, consider three (3) for the greatest importance and one (1) for the child, which allows to put and hierarchize these indicators.

Table 3. Proposal for fields and attributes

Fields	Level of importance 3 2 1	Attributes	Level of importance 3 2 1
Structure		Loads	
		Resistant capacity	
		Unions	
		Structural elements	
		Non -structural elements	
		Electrical installations	
		Hydraulic facilities	
		Sanitary facilities	
		Fuel facilities	
		Technological facilities	
Functionality		Processes	
		Flows	
Health and security		Air pollution	
		Water pollution	
		Light pollution	
		Visual pollution	
		Sound pollution	
		Electromagnetic pollution	
		Thermal contamination	
		Psychological effects	
		Electrocution danger	
		Danger of diseases	
		Accident danger	
Environment		Living beings	
		Climate	
		Natural resources	
Economic affectation		Economic activity	
		Production process	
		Affectation to third systems	
Comfort		Visual comfort	

	Hygrothermic comfort
	Acoustic comfort
	Olfactory comfort
	Psychological comfort
	Comfort for oscillations
Aesthetics	Concepts
	Forms
	Colors
Availability	Specialized labor
	Special materials
	Advanced technology
Repair cost	Labour
	Materials
	Technology
Value	Patrimonial
	Archaeological potential
	Cultural
	Social significance
	Authenticity
Quality	Property of materials
	Element design
	Integrity

For the determination of the sum of the levels of importance where all the fields and attributes affected by an injury are included, equation (2) is proposed.

$$\Sigma Ni = \sum [Nic + \sum Pa] \tag{2}$$
Where:

Ni: Importance levels
Nic: Levels of importance of fields
Pa: Weight of the attributes

The weighting of the attributes will be related to the level of importance of them, so that:
Level of importance 3 = 0,75
Level of importance 2 = 0,50
Level of importance 1 = 0,25

To determine the impact index, Table 4 is proposed, which contains three combination of intervals and in turn respond to an impact level, severe, moderate or perceptible.

Table 4. Adjustment proposal for impact

Impact	Index impact	of ∑ Levels of importance 1	2	3	Description
Severe	3	> 10	> 20	> 25	The impact will be taken into
Moderate	2	5- 10	15- 20	15- 25	account according to the number
Perceptible	1	< 5	< 15	< 15	of fields and attributes that affect
Selection					the same deterioration

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When determining the detectability index of an injury, the difficulty in detecting and/or carrying out the pathological study of this, associated with the resources required for it must be analyzed. Table 5 shows the proposal to accept or not by the experts and if the criterion in this regard is considered appropriate.

Table 5. Detectability index proposal

Detection	Index of detectability	Description
Low	3	There are few possibilities to detect the appearance of primary injury (expert opinion and technology are required)
Medium	2	The probability of detection of the primary lesion is moderate (expert opinion is required)
High	1	It is usually easy to detect the appearance of the primary lesion (anyone can detect the appearance)

Once the frequency, impact and detectability indices are proposed, the criticality index for equation (1) can be determined, but the value obtained from this index does not provide limits to the intervals of the criticism levels, that is why the analysis is proposed through the critical pattern matrix. For three levels of criticality, a 3x3 matrix (Table 6) is defined based on a colored code that specialists must define. In this matrix, the intersection of the lower values of frequency and impact indices correspond to the lower levels of criticality of the deterioration with these conditions.

Table 6. Proposal for critical matrix

Criticality matrix		Impact		
		1	2	3
Frequency	3			
	2			
	1			
Criticality levels				
High (A)		Medium (M)		Low (B)

Adjustment proposal for the impact method. The method has 16 parameters that do not conform to the conditions of a building, so they will be presented to the specialists for the selection of those who best adapt to the characteristics of the studio object. It was necessary to adapt the terminology in some parameters (Table 7). For each lesion, all the pars must be analyzed and their category in A, B or C, depending on the conditions of the element evaluated and the description that is closer to the reality of their status. Category A corresponds to the deterioration of the highest level of criticality, category B at the average level of criticality and category C, those of low level of criticality.

Table 7. Proposal for parameters and categories

Parameters	Description of the categories	Acceptance
Interchangeability: It consists of the ease of being replaced the deteriorated element by a similar one	A. If the element affected by this deterioration is irreplaceable, or its work cannot be done by any other component B. If your function is replaced by another element C. If your function can be executed by any other similar element	Yes___ No___
Operation regime:	A. Deterioration that prevents the operation of the	Yes___

Refers to the possibility that the element can fulfill its function with the presence of deterioration	element that affects	
	B. Deterioration that affects to some extent the operation of the element	No___
	C. Deterioration that does not affect the operation of the element	
Use level: This represents the useful life of each building parameter	A. The most commonly used elements, that any need for corrective maintenance would affect the building	Yes___
	B. They are less used, there may be maintenance without affecting other	No___
	C. Very little used, there may be maintenance without affecting other elements	
Main parameter: It refers to a characteristic parameter of the element that guarantees the quality of its function	A. Those who have the parameter of greater functional or structural value	Yes___
	B. Those of medium value	
	C. Low value	No___
Maintainability: Corresponds to the ease of executing maintenance, accessibility to its parts and components, according to its construction characteristics	A. Deterioration in elements of little maintainability, difficult to access its parts, that is, difficult to detect and repair	
	B. They are medium complexity, where access is not so difficult to all components	Yes___
	C. Deterioration in elements of little complexity and high maintenance, where access is easy for almost all components	No___
Conservability: Reflects the sensitivity of its resistance to the environment that surrounds it, that is, the deterioration produced by the aggressiveness of the environment	A. Deteriorates that appear due to the aggressiveness of the environment in which the element is located	
	B. Deterioration that appears due to the inadequate exploitation of the element	Yes___
	C. Deterioration that appears product to normal exploitation and time use conditions	No___
Automation degree: This parameter evaluates the degrees of freedom of the element to work without the action of man	A. Automated elements, which practically work without the action of man	Yes___
	B. Semi -automatic elements, man has to intervene	
	C. Non -automatic elements	No___
Operational security: It consists in evaluating the extent that the element can affect man	A. These are deterioration that generate great impact on security, their existence is very dangerous	Yes___
	B. Are those that can cause less serious impacts	
	C. They are little dangerous and do not offer insecurity	No___
Deterioration value: It is the value at the time of diagnosing and repairing a deterioration, it refers to equipment and materials for its detection, evaluation and repair	A. The deterioration that requires the greatest value	
	B. Those of moderate value	Yes___
	C. Those of lower value	No___

Provisioning feasibility: It refers to the ease that exists to guarantee the supplies of equipment and materials for the maintenance and repair of a deterioration	A. Those deterioration with serious difficulties in repair supply B. Those who have assured the supply of some equipment and materials C. Those who have great possibilities of equipment and material supplies	Yes___ No___
Exploitation conditions: Takes into account the conditions that characterize the exploitation of the element	A. These are deterioration that make the exploitation of the element make B. Deteriorates that modify the exploitation conditions of the element C. Will be those who do not interfere with the exploitation of the element	Yes___ No___
Environmental protection: It refers to the possible affectation to the environment produced by the existence of deterioration	A. Are the deterioration that directly affect the environment B. Those who affect it to some extent, indirectly C. Those that do not affect the environment at any time	Yes___ No___
Preceding behavior: It refers to the repeated appearance of a deterioration in the same element	A. Deterioration that appears periodically in the same element B. Deterioration that appears sporadically in an element C. Deterioration that appears for the first time	Yes___ No___
Operator qualification: Is related to the level and skill of the operator who has the responsibility for the maintenance and repair of the element	A. The operator requires great specialization to undertake the repair of a deterioration B. The operator that requires some specialization for certain activities C. The operator does not require specialization	Yes___ No___
Characterization of repair work: It refers to the need to rigorously control the activity carried out by the operator in the repair of a deterioration	A. Maximum demand in the control of a job B. Requires moderate control C. Does not require control during work	Yes___ No___
Value of the work time of deterioration: It refers to what it costs to produce an hour of work during the exploitation of the element	A. Greater work time value B. Lower work time value	Yes___ No___

Adjustment proposal for the Pareto technique. In the literature it is recommended, in the case of reliability studies through this method, to carry out the statistical analysis from the frequencies of occurrence of a fault [10], but this parameter is not the one that generates the greatest consequences in the construction sector, so it is proposed to analyze statistically, in addition, the impact that existing lesions can generate. For the analysis, the deterioration counting or percentage of the affected area will be taken as frequency values, and in the case of the impact analysis, the sum of the importance levels of the affected fields will be taken in the same way as in the case of the case of the criticality analysis.

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3 Results and discussion

For data processing through the Delphi method, absolute frequency tables and accumulated relative frequencies were built. The images of the relative frequency values   accumulated by the inverse of the normal curve were determined, to determine the cutting points, which formed the intervals to define the category of each aspect consulted. After all the analysis of the averages and verify that all the proposed aspects have a category according to what the experts consulted through the questionnaire, the definitive tools for the criticality analysis, the method of the impacts, are set up the impact method and the analysis of the impact on the Pareto technique, from the consensus of the specialists.

Validation of criticality analysis

In the adjustment and validation of the frequency index, in the first round, no specialist selected more than 90% occurrence, for a high frequency, and only one of them considered 80% as a lower limit for this same category. The combination 2 was final for frequency analysis, for a frequency low the values   below 15% occurrence and for high above 60%.

In the impact analysis, the total of the specialists considered the structure field such as the most important, where the affectation of all constructive elements of the building is considered, unlike the aesthetics, which was selected by 14 experts and only one considered its importance. All fields and attributes were accepted by experts. The structure, functionality, health and security and environment fields obtained the greatest importance, while only the aesthetic field was considered with importance 1. In the total attributes belonging to structure, functionality, availability and repair cost consensus in the value 3 of importance for a weighting of 0.75, as well as the pollution of air and water and the attributes danger of electrocution, of diseases and accidents, as well as the affectation to living beings, heritage value and heritage and integrity of the elements. The rest of the attributes were classified with importance 2, which translates into a weighting of 0.50. No attribute obtained low importance.

The selection of combinations to define the severity of the impact generated by deterioration did not present important differences, which shows that in evaluations that require qualitative assessments, there is great diversity in the criteria of experts. In the second round the consensus of the experts was achieved, that is, that when the sum of the importance of the affected fields is greater than 20, it is considered a severe impact.

The equation for determining the sum of importance was accepted by specialists as well as the detectability levels and indexes presented. All the specialist accepted the proposed criteria, so no observations were made on these.

The pattern matrix to determine the levels of criticism was formed as shown in Table 8. In the cells that contain the extreme values   of the frequency and impact indices, the total respondents selected high level of criticality for the cell 3.3 and low level of criticality for cell 1.1.

Table 8. Matrix criticality pattern

Criticality matrix		Impact		
		1	2	3
Frequency	3			
	2			
	1			
Criticality levels				
High (A)		Medium (M)	Low (B)	

Validation of the impact method

The 16 parameters and categories of the impact method, presented to experts, were acceptable to consider in the tool. These parameters and their categories were described in Table 7. The degree of automation parameter was the least selected by the experts, however, the authors are successful this result by not corresponding to the characteristics of the component elements of the building that is intended to evaluate, because in this case, very few elements depend on the actions of man to perform his function.

4. Conclusions

The adjustment of the criticality analysis, the impact method and the incorporation of the impact analysis in the Pareto technique allow its application to determine the constructive technical state of the buildings, from the parameters, attributes and categories validated to be established for This type of evaluations, which determines the level of criticism of the deterioration identified. Through these tools, the integral evaluation of the buildings is achieved by considering the influence on constructive injuries on functionality, health and safety, environment, comfort, aesthetics, value, quality, economic affectation, availability and repair cost.

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Conflict of Interest

There is no conflict of interest.

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