ENGLISH VERSION.........

Management model with processes to identify seismic vulnerability in housing

Modelo de gestión con procesos para identificar la vulnerabilidad sísmica en viviendas

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Abstract

Seismic events for decades have caused great prejudice to countries causing human and economic losses due to the collapse of houses, therefore the relevance of this research lies in offering a management model with processes to identify the seismic vulnerabilities of houses and validate the correlation between whether there is dependence between the Knowledge of the Management Model with Processes and its application (hypothesis). A mixed method (quantitative and qualitative) is presented, generating reliable and concise results, issuing Chi-Square values to prove that they are greater than 0.05, implying a very weak or low dependence relationship. Consequently, it is concluded with a confidence level of 95%, indicating the way in which the knowledge of the model is developed and its application, has very little dependence in the local governments of the Moquegua Region, since they do not know the proposed model.

Keywords: Model; process management; seismic vulnerability; housing

Resumen

Los eventos sísmicos durante décadas han ocasionado pérdidas humanas y económicas debido al colapso de las viviendas, por ello la relevancia de esta investigación radica en ofrecer un modelo de gestión con procesos para identificar las vulnerabilidades sísmicas de las viviendas. Se presenta un método mixto (cuan y cual) generando resultados fiables y concisos, emitiendo los valores del Chi Cuadrado para comprobar que son mayores 0.05, implicando una dependencia relación muy débil o baja. Consecuentemente, se concluye con un nivel de confianza del 95%, indicando la forma en que se desarrolla el conocimiento del modelo y su aplicación, tiene muy escasa dependencia en los gobiernos locales de la Región Moquegua, puesto desconocen el modelo propuesto..

Palabras clave: Modelo; gestión con procesos; vulnerabilidad sísmica; viviendas

1. Introduction

Frequently in Latin America, there are earthquakes or seismic events caused by structural damage in the layers of the earth, causing human and economic losses, among others (Moncayo et al., 2017). Peru does not escape this risk as it is located on the western edge of South America. This region is considered to be at high risk of earthquakes due to the subduction of the tectonic plates that convergein the country, including the Nazca Plate (Oceanic) under the South American Plate (Continental). It is also located in the Pacific Ring of Fire, an area of volcanic activity. (Bono et al., 2021).

In view of the above, there is a risk inherent to tectonic movements called seismic vulnerability, which has caused significant economic and human losses in Peru due to the inadequate control in the construction of houses and buildings, with 75% of the victims between 1900 and 1992 being due to the collapse of housing (Kuroiwa, 2005). It is important to mention that the seismic vulnerability of housing is a set of parameters (year of construction, height, type of housing and irregularities in plan and elevation) capable of predicting the type of structural damage, the failure mode and the carrying capacity of a structure under probable seismic conditions (Preciado et al., 2020) and (Escamirosa et al., 2018).

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In addition, it is necessary to change and innovate to face the ongoing challenges by involving human capital through a competency-based management (CPM) tool, monitoring constructions and determining the risk level of existing buildings. We seek to minimize or eliminate non-compliance with the existing regulations in Perú (which is the country where the research was conducted), such as the Supreme Decree No. 003 issued by the (Ministry of Housing, Construction and Sanitation 2019) (Ministerio de Vivienda, Construcción y Saneamiento, 2019), in order to avoid human and economic losses. For this reason, (Alles, 2007) and (Rabago, 2010) mention the CPM as a resource to transform the communication channel between employees and the institution where they work. Increasing the knowledge and best practices of those involved can optimize the procedure to identify the seismic vulnerability of housing.

It is necessary to point out that the CPM is based on transferring all the knowledge through processes (for this reason, it is also known as Process Management) to the employees of a company or institution to generate its appropriation and modify their behavior when carrying out their activities. This case seeks to identify the greatest number of seismic deficiencies in the structural design of housing by validating a process management model to be implemented by the national government, and that can be replicated in other countries, taking as a reference center the region of Moquegua in Peru, considering that, compared to other regions, Moquegua-Tacna (210 x 130 km²) has a high percentage of occurrence of an earthquake of magnitude M 8.2. (Tavera, 2020).

2. Materials and methods

This is basic research as it is focused on providing new theoretical knowledge to the field of management for the identification of seismic vulnerability in housing and seeking an answer to the problem of the lack of a process management model for the prevention of natural disasters caused by the movement of tectonic plates that affect a region. In this case, the research was carried out in the Moquegua Region due to its seismic characteristics. It is important to point out that recent seismic activity in the department of Moquegua is dated June 23, 2001, in the 21st century, and reached a magnitude of MW 8.4 on the Kanamori scale. In this regard, (Hough, 2019) said that this is the most reliable scale to measure the magnitude of the event in terms of the energy released. Undoubtedly, this last earthquake caused significant damage to the city of Moquegua, resulting in the death of twenty-two people, 277 injured, and 57467 victims, in addition to 4062 dwellings affected and 2738 destroyed (Kuroiwa, 2005).

Also, the population under study is composed of two strata. The first is related to the number of dwellings in the Moquegua region, with 9,461,778 individual dwellings and 7,969 collective dwellings, totaling 9,469,747 according to (INEI, 2021a). Purposive sampling is applied to calculate the sample, as stated by (Baena, 2014) and (Hernández and Mendoza, 2018). Through this method, the elements are chosen based on the criteria and judgments of the researchers. Therefore, a population center was selected to implement the proposal, considering all the existing dwellings in the town of San Francisco. This pilot environment was selected because it is one of the centers with the highest population density in the region, has a high level of seismic risk and is accessible to the researchers. A total of 1,399 dwellings was determined. (INEI, 2021b).

For the second stratum, the population is composed of the public agents in charge of complying with the technical standard e.030 "Seismic Resistant Design" (Ministerio de Vivienda, Construcción y Saneamiento, 2019) of the dwellings in the District Municipalities and Minor Population Centers of the Moquegua Region. In this case, 31 subjects will be included in a population census because it is a finite number manageable by the researchers. It is worth noting that the above-mentioned design complies with the appropriate structural regulations in terms of dimensions, materials, proportions, and resistance of the dwellings to save lives and minimize material damages (Pan American Health Org, 2000).

For this study, the mixed methods research (Qualitative and Quantitative) was applied through the observation technique (analytical method) and the survey (descriptive statistics). The procedure was based on the analysis of the international method of Rapid Visual Screening of Buildings for Potential Seismic Hazards, developed by the Federal Emergency Management Agency, known as FEMA 154. This standard applies to all structures located in telluric risk areas (Parrales et al., 2018), determining the technical and information requirements to be included in the management model with the proposed process and adapted to the region's reality. Also, a survey was conducted among the individuals involved in the acceptance or rejection of the process management model to identify the seismic vulnerability in the population centers of each jurisdiction and validate the proposal.

In addition to the above, the management plan was prepared with processes determining the inputs, outputs and the development of the processes for identifying the seismic vulnerability of housing, based on the FEMA 154 format, with aspects added to the proposed model, applying it to the dwellings chosen as a sample. Then, the data were processed according to the type of construction material, functionality and number of floors of the dwelling. Its vulnerable areas were identified and verified if it complies with the e.030 standard of the national building regulations.

To support the above, vulnerability plans, plans of housing material types and the number of floors of the dwelling were designed considering the technical criteria in the field of engineering and the process management model.

3. Results and discussion

The results are organized to provide answers to two specific objectives: i) to determine the degree of knowledge of workers on the application of the seismic vulnerability identification model, and ii) to validate the design of a new process management-based model to identify seismic vulnerability in housing.

For this reason, after applying the corresponding analysis process to the survey and providing an answer to the first objective of the research, the results showed that the level of interest in using the model is evident, with 96.77% of high acceptance in the application of the process management model to identify seismic vulnerability by local governments.

(Table 1) and (Table 2) show the average behavior of interest in using and applying a process management model in local governments. The sum of the indicators' averages reaches the value of 19.51. This score is placed in the high level of interest in the application of the model. The standard deviations of the answers indicate that local governments do not know or are unaware of their functions in this regard. In conclusion, local governments show a high interest in using the management model, as analyzed from the data collected. Also, there is a low budget and Little awareness regarding the identification of Seismic Vulnerability.

Table 1. *Application of the management model and its statistical analysis*

Characteristic	Mean	Standard deviation
Application of the Model	3.903	0.339

Table 2. *Management model and its statistical analysis*

Characteristic	Sum	Standard deviation
Management Model	19.516	0.339

By deepening the analysis and establishing a level of confidence in the results, the following hypothesis test is developed for the mean of the answers, considering the following assumptions:
H0: $\mu < 16$ - Low interest in the application of the model.
H1: $\mu \geq 16$ - High interest in the model
α: 5% - Significance level.
$n = 31$

The t-distribution, a mathematical model, used in small, normally distributed populations, was applied (Ñaupas et al.,2014). The values of the t-distribution obtained from the statistical analysis are replaced, and the hypothesis test for the mean is calculated with the following (Equation 1):

$$Z = (X - \mu) / (S/\sqrt{n}) \quad (1)$$

When replaced, this generates (Equation 2):

$$Z = (19.513 - 16) / (0.339 /\sqrt{31}) = 56.78 \quad (2)$$

Given the "t" statistic value obtained is greater than that specified in theassumption (56.78), the H0 is rejected, and the alternative hypothesis (H1) is accepted. This indicates the existence of a high interest in the application of the proposed model for the identification of the seismic vulnerability of housing in the Moquegua region with a confidence level of 95%. For this reason, we proceed to the acceptance of the research hypothesis.

Based on the above, the reports in (Table 3) indicating the correlation coefficients are considered for testing the hypothesis.

Table 3. *Correlation coefficients*

	Value	**gl**	**Asymptotic sig. (bilateral)**	**Exact sig. (bilateral)**	**Exact sig. (unilateral)**
Pearson's Chi-square	.11(b)	1	.739		
Continuity correction (a)	.000	1	1.000		
Likelihood ratio	.207	1	.649	1.000	.903
Linear by linear association	.107	1	.743		
No. of valid cases	31				

The valued decision rule was as follows:

Si X2 < 0.05 There is a dependence between the Knowledge of the Process Management Model and the application of the Model.

Si X2 > 0.05 There is no dependence between the Knowledge of the Process Management Model and its application.

Therefore, the Chi-Square values show that there is independence between the Knowledge of the Process Management Model and the application of the Model, which are greater than 0.05. This implies a very weak or low dependence relationship between the knowledge of the model and its application. Accordingly, a confidence level of 95% is reached, indicating that the way the knowledge and the application of the model is developed depends very little on the local governments of the Moquegua Region since they are unaware of the process management model for the identification of the seismic vulnerability of housing in the local governments of the Moquegua Region.

Subsequently, in order to provide an answer to the second objective, the identification of the seismic vulnerability of housing was applied through the model built for this purpose, which was implemented in the San Francisco area, and the following statistical data were generated:

Table 4. *Results obtained for dwellings by type of material*

Type of material	**Number of dwellings**	**Percentage**
Brick	993 dwellings	70.98 %
Adobe	209 dwellings	14.94 %
Block	055 dwellings	03.93 %
Wood	069 dwellings	04.93 %
Matting	073 dwellings	05.22 %
Dual	000 dwellings	00.00 %
TOTAL	1.399 dwellings	100.00 %

(Table 4) shows that 70.98% of the dwellings in the population center under study are built of brick, 14.94% of adobe, 05.22% of matting, 4.93% of wood and 03.93% of block.

(Table 5) shows the results of the housing census involved in the study

Table 5. *Results obtained for dwellings by floor number*

Number of floors	Number of dwellings	Percentage
First Floor	812 dwellings	58.04 %
Second Floor	476 dwellings	34.02 %
Third Floor	111 dwellings	07.93 %
Fourth Floor	000 dwellings	00.00 %
Fifth Floor	000 dwellings	00.00 %
Sixth Floor	000 dwellings	00.00 %
TOTAL	1399 dwellings	100.00 %

(Table 6) shows the consolidated Medium-high vulnerability result in the population center of San Francisco applying the process management model, showing the effectiveness of the application of the new model, which has an impact on the number of lives that can be saved if corrective measures are applied on time to the structure of the dwellings.

Table 6. *Identification of seismic vulnerability in the population center of San Francisco in the Province of Mariscal Nieto, Moquegua Region*

<table>
<tr><th>Type</th><th>Number of dwellings</th><th>%</th><th colspan="2">Index</th><th>Category</th></tr>
<tr><td>Type 1</td><td>282 dwellings</td><td>20.16%</td><td rowspan="5"></td><td rowspan="2">75.48%</td><td rowspan="2">High vulnerability</td></tr>
<tr><td>Type 2</td><td>774 dwellings</td><td>55.33%</td></tr>
<tr><td>Type 3</td><td>343 dwellings</td><td>24.52%</td><td rowspan="2">79.84%</td><td rowspan="2">Medium vulnerability</td></tr>
<tr><td>Type 4</td><td>0 dwellings</td><td>0.00%</td></tr>
<tr><td>Total</td><td colspan="2">1399</td><td>24.52%</td><td>Low vulnerability</td></tr>
<tr><td colspan="6">Result: Medium-high vulnerability</td></tr>
</table>

The proposal for the identification of seismic vulnerability through the new Del Carpio 1.0 [eiv-rd1c] format is detailed below (see (Table 7)).

***Table 7.** DELCARPIO 1.0 format*

Sector		
Block		
Plot		
Construction Type		
Structure	Soil factor	Slopes
Soft floor	Z1	0% - 3%
Short column	Z2	3% - 5%
Irregular height	Z3	5% - 10%
Uneven walls	Z4	10% - 15%
Lack of rigidity of walls in one of its axes	Expected conditions	15% - More
Number of floors	Structure Deterioration	Hydrology
1°	01 - 25	Landslides
2°	25 - 50	Liquefaction
3°	50 - 75	Settlements
4°	75 - 100	
5° or more	Existence of fissures	
	Existence of cracks	
Geometric parameters	Observations:	
Torsional composition		
Ideal		
Acceptable		
Poor		
Robustness		
Ideal		
Acceptable		
Poor		

The evaluation of dwellings through the improved format known as Del Carpio is based on the following criteria:

Type 1: Seismically very weak: old buildings (older than 100 years) of adobe, pieces with dimensions of 50x30x13 cm, walls of 0.30 or 0.50 m wide without vertical or horizontal reinforcements, with flexible roofs with wooden beams forming trapezoidal trusses on which wooden slats are placed with mud cake, this type of roof is known as "Mojinete." Buildings with adobe walls, with dimensions of 40x30x12 cm, resulting in walls of 0.20 and 0.40 m wide and 2.5 m high, with stone foundations with mud of 0.40 m deep, without vertical or horizontal reinforcements in the walls, with a light roof consisting of wooden beams covered with cane and mud cake and also corrugated sheets of zinc or asbestos-cement.

Type 2: Seismically weak: old buildings of wood and quincha, with structural members weakened by the action of successive wetting and drying, with a flexible mojinete-type roof covered with wooden slats or cane with mud cake or corrugated sheets of zinc or asbestos-cement. Buildings of masonry walls whose units are bricks (29x15x9 cm) and blocks (30x18x13cms) of handmade concrete of regular to low quality, joined with sand-cement mortar, concrete strip foundation, with or without reinforcement in concrete columns, without tie beams, with a flexible and light roof made of wooden beams covered with canes with mud cake, corrugated sheets of zinc or asbestos-cement. As an *additional theory to this type, some buildings use tubular units for the construction of load-bearing walls in the first place as upper floors, informally self-constructed. In the same way, buildings that present the configuration of brick of 24x14x9 cm in the first level and in the second level, clay blocks and adobe reinforced with electro-welded mesh or polymer mesh.*

Type 3: Semi seismic-resistant: are constructions with brick masonry walls or concrete blocks, handmade of regular to low quality, joined with mortar, manufactured, with columns and tie beams and a light rigid roof, self-built in an informal manner, without having received any technical advice, and the clay units will be solid.

Type 4: Seismically resistant: buildings of masonry walls with units made of manufactured bricks of clay or concrete, or good quality concrete blocks, joined with sand-cement mortar, with columns, tie beams and light or heavy rigid roof of reinforced concrete, built with technical advice. As an additional theory to this type, there are buildings with walls of limited ductility:

- *High vulnerability: the area where Type 1 and Type 2 buildings represent more than 75% of the total.*
- *Medium-high vulnerability: the area where Type 1 and Type 2 buildings represent more than 50% of the total.*
- *Medium vulnerability: the area where Type 2 and Type 3 buildings represent more than 50% of the total.*
- *Medium-low vulnerability: the area where Type 3 and Type 4 buildings represent more than 50% of the total.*
- *Low vulnerability: the area where Type 3 and Type 4 buildings represent more than 75% of the total.*

The percentages defined by the researcher to be used in the proposal are detailed below:

(Table 8) shows the percentages to be used in the new formats to perform the necessary seismic vulnerability calculations.

Table 8. Percentage of assigned value for seismic vulnerability parameters

Measurement	Minimum score	Maximum score
Low	15%	32%
Medium-low	32%	49%
Medium	49%	66%
Medium-high	66%	83%
High	83%	100%

**Note: the correction factor will be increased by 30% if there is no stiffness in any of the axes of the walls.*

(Table 9) shows the values defined by the researcher to qualify the soil types under study.

***Table 9.** Percentage of assigned value for soil type parameters*

Soil	Measurement	Score
	Z1	3%
	Z2	7%
	Z3	11%
	Z4	15%
	Esp. cond.	Prorate

**Note: the parameters of the National Building Regulation E.030 Seismic-resistant design zone factor will be increased.*

(Table 10) shows the scores to be used in the DELCARPIO format related to topography.

Table 10. *Percentage of assigned value for topography parameters*

Topography	***Measurement***		***Score***
	Low	*0% - 3%*	*2%*
	Medium-low	*3% - 5%*	*4%*
	Medium	*5% - 10%*	*7%*
	Medium-high	*10% - 15%*	*10%*
	High	*15% - More*	*13%*

**Note: if the hydrology study is required, 5% will be subtracted, and the topography will take the value of 8% as new values.*

Considering the type of slope, the score established in (Table 11) is assigned.

Table 11. Percentage of assigned value for modified topography parameters

Topography	**Measurement**		**Score**
	Low	0% - 3%	1%
	Medium-low	3% - 5%	2%
	Medium	5% - 10%	4%
	Medium-high	10% - 15%	6%
	High	15% - More	8%

The description of the slopes is detailed below:

- *High slope: if the average slope per area exceeds 15% or more.*
- *Medium-high slope: if the average slope per area ranges from 10% to 15%.*
- *Medium slope: if the average slope per area ranges from 5% to 10%.*
- *Medium-low slope: if the average slope per area ranges from 3% to 5%.*
- *Low slope: if the average slope per area ranges from 0% to 3%.*

(Table 12) shows the score to be used in the format according to the number of floors of the dwelling.

Table 12. Percentage of assigned value for the parameters of number of floors

No. of floors	Measurement	Score
	1°	1%
	2°	2%
	3°	3%
	4°	4%
	5° or more	5%

Considering the deterioration of the structure, (Table 13) shows the stipulated percentages.

Table 13. *Percentage of Value Assigned for the Deterioration Parameters of the Structure*

Deterioration	Measurement		Score
	01 - 25	years	2%
	25 - 50	years	4%
	50 - 75	years	7%
	75 - 100	years	10%
	Existence of fissures		5%
	Existence of cracks		10%

**Note: if there are fissures and aging, the results are averaged.*

In relation to the geometrical parameters according to their torsional composition, the consolidated score will be established in (Table 14).

Table 14. Percentage of Value Assigned for the Geometric Parameters of the Structure

Geometric Parameters	Measurement	Score
	Torsional Composition	
	IDEAL: LENGTH = WIDTH	4%
	ACCEPTABLE: LENGTH < 4* WIDTH	6%
	POOR: LENGTH > 4* WIDTH	7%
	Robustness	
	IDEAL: HEIGHT ≤ WIDTH	4%
	ACCEPTABLE: HEIGHT ≤ 3* WIDTH	6%
	POOR: HEIGHT > 3* WIDTH	7%

**Note: the highest percentage of the sample obtained is chosen, and it is divided by two to obtain the result of Geometric Parameters.*

Regarding hydrological parameters, those stipulated in (Table 15) will be used.

Table 15. Percentage of Value Assigned for Hydrological Parameters

Hydrology	*Measurement*	*Score*
	Landslides	*5%*
	Liquefaction	*5%*
	Settlements	*3%*

**Note: it will only be applied if necessary.*

Finally, the sum of all these parameters will provide the final result for the identification of seismic vulnerability (See (Table 16)).

Table 16. *Value assigned for the vulnerability identification parameters with the DELCARPIO 1.0 format*

Measurement	*Score range*	
Low	*30%*	*44%*
Medium - low	*44%*	*58%*
Medium	*58%*	*72%*
Medium - high	*72%*	*86%*
High	*86%*	*100%*

**Note: if the hydrology study is required, 5% will be subtracted, and the topography will take the value of 8% as new values.*

4. Final thought

A macro based on process management was developed through the analysis carried out and the validation of its effectiveness with the persons in charge of identifying the seismic vulnerability in the areas of Moquegua. This is the first step in the four-step improvement process, which has a distinctive letter for its codification (see Figure 1), allowing to make an early warning of the structural seismic vulnerability of housing in any region with medium-high seismicity.

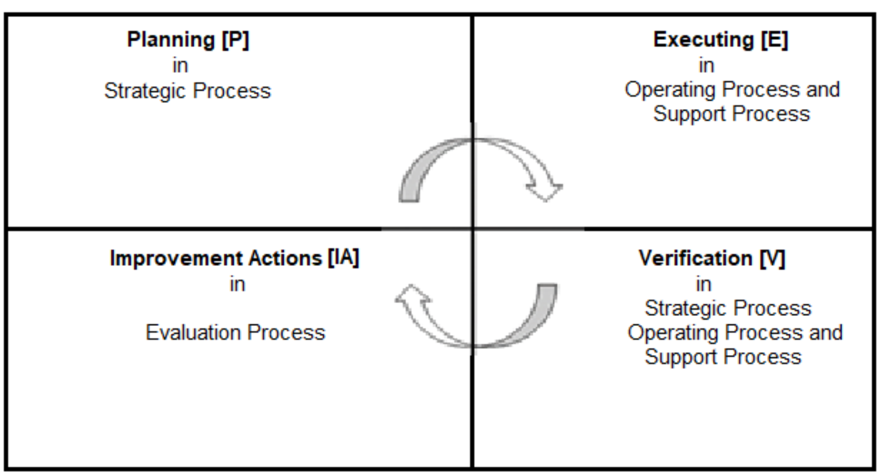

Figure 1. Map of Macro Processes for the Identification of Seismic Vulnerability.

(Figure 2) shows the map with the processes and departments involved, based on the information observed, the knowledge provided by the specialists in seismic structures in the region and the project information.

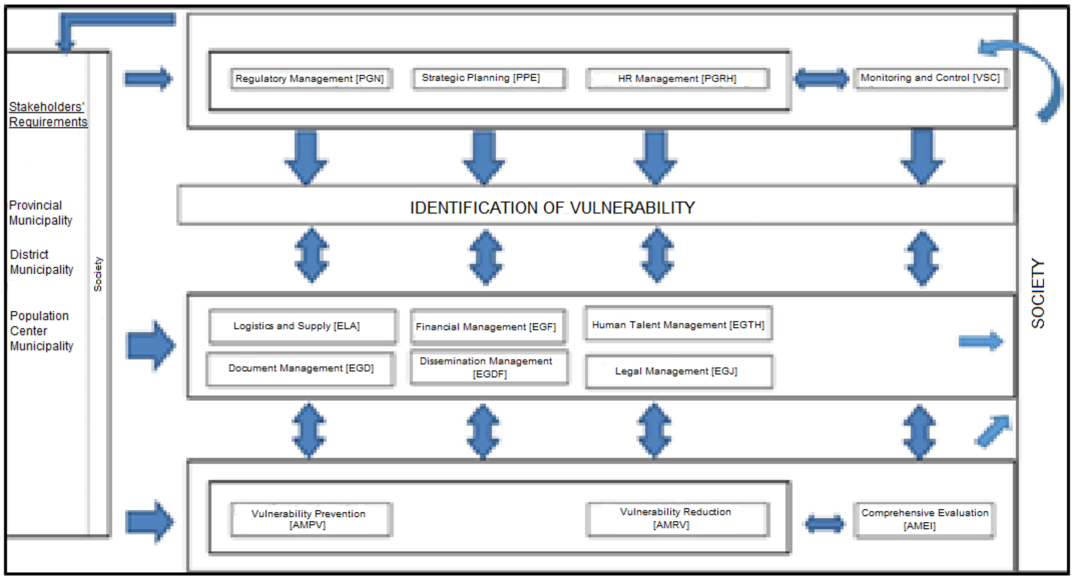

Figure 2. Map of Processes for the Identification of Seismic Vulnerability

In this sense, (Candebat and Godínez, 2018) state that this last data is not necessary to perform the evaluation since significant parameters were considered in the instrument designed to obtain accurate results. They also agree with what was expressed by (Álvarez, 2016), who emphasizes that for a long time, the lack of maintenance in dwellings has an impact on their deterioration, making them more susceptible to suffer significant damage in cases of medium-high magnitude earthquakes.

Subsequently, through this research, the construction and application of the form designed to determine that 30% of the general sample has a value higher than 2 and 70% of the sample has a value lower than 2, corresponding to structural failures in its construction, foundations, soil typology-level failures, joints between columns and beams, door openings, critical damage in windows. This places the seismic vulnerability of housing in the medium-high range. These incidences are consistent with the studies conducted by Loor, (Palma and Garcia, 2021), in which the vulnerabilities of the dwellings of the Santa Marianita sector in Ecuador are detected. It was agreed with the elite of each government to promote efforts to guarantee the access to credits or aids directed to the inhabitants of the dwellings that show seismic vulnerability, maximizing the quality of life, the proper habitability and safety against possible seismic events.

5. Conclusions

1. A model validated by experts based on process management (knowledge of processes by workers) was obtained so that the persons in charge of identifying the seismic vulnerability of housing in an area can determine their degree of risk. This way, the regional government can take preventive measures in the event of an earthquake, avoiding human and economic losses.

2. The instrument developed includes the evaluation of analyzed parameters that directly affect the behavior of the housing structure.

The proposed model was applied to 1,399 dwellings located in the population center of SanFrancisco in the Province of Mariscal Nieto, Moquegua Region. The model showed a medium-high level of vulnerability in the dwellings. This means that they do not comply with the requirements of the technical standard e.030 "Seismic Resistant Design" issued by the Peruvian Ministry of Housing, Construction and Sanitation.

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