1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.22

Proposal for a suitable workflow for assessing the seismic vulnerability of historical buildings, Atlixco (Puebla, México) as a case study

Rafael Ramírez Eudave[1], Tiago Miguel Ferreira[2]

[1] *PhD candidate*, University of Minho, Institute for Sustainability and Innovation in Structural Engineering, *r.92@outlook.es*

[2] *Postdoc Researcher*, University of Minho, Institute for Sustainability and Innovation in Structural Engineering, *tmferreira@civil.uminho.pt*

Abstract

The assessment of the seismic performance of historical buildings faces numerous challenges, mostly related to the diversity of the building stock and the uncertainties associated with the characterisation of the structural and construction systems. However, such assessment is essential, not only considering the human and material losses that can stem from the poor seismic performance of these buildings but also due to the role that historical constructions play in terms of housing and economic activities, particularly in the context of urban historical centres. Several approaches are currently available for this purpose. Among those, index-based methods have been gaining momentum worldwide due to their excellent balance between simplicity and accuracy. These semi-quantitative techniques, known in the literature as first-level approaches, permits to estimate the levels of damage for specific seismic intensities based on a ponderation of a series of structural and architectonic characteristics. However, so that the outputs obtained from these methods can be considered reliable, it is fundamental to adopt data collection strategies that can be simultaneously expeditious but capable of offering high-quality information. At present, Geographic Information System (GIS) tools are valuable databases for storing a wide variety of information. Moreover, the democratisation of portable informatic devices, namely smartphones and tablets, has enabled to decentralise those databases, speeding up processes and making work more collaborative. This paper details a suitable workflow that considers the use and adaptation of open-source tools, starting from creating a GIS database, the design of a survey specifically tailored to feed an index-based vulnerability-assessment approach, and its implementation in an open cloud service and its distribution through open-source smartphone apps. The city of Atlixco (Puebla, Mexico) and the September 19th, 2017 earthquake are used here to analyse and discuss the application of such a workflow in a real case-study.

Key words: Vulnerability assessment, Vulnerability Index Method, Geographic Information System, Historical Buildings, Masonry Constructions

1 Introduction

The seismic vulnerability assessment of the existing building stock has to face numerous challenges, namely related to the number of samples existing in the urban contexts. Furthermore, the analysis of historical buildings (mostly based on masonry structures) intrinsically adds numerous uncertainties to the process, frequently related to the nature of materials. Hence, the implementation of wide-scale strategies for assessing constructions based on simplified parameters would help to proactively identify the vulnerability status of entire clusters of buildings. It is important to recall that many historical structures are still in use for housing, commerce and other relevant activities. The anticipation of potential damages and losses in earthquakes is relevant for the design of mitigation strategies and emergency management plans, increasing the resilient capacities for entire urban cores.

2 Motivation

On September 7th, 2017, an M_W = 8.2 seismic event hit the south of Mexico. More than 63,000 houses were damaged in 107 municipalities [1]. Damages also included more than 100 cultural assets and substantial loses in critical infrastructures, such as health facilities, schools and road communications. A few days later, an M_W = 7.1 earthquake hit the country's centre, affecting Mexico City and the surrounding areas. Preliminary information declared around 5,765 damaged buildings, including 46 collapses (in Mexico City only). At a national level, more than 150,000 buildings were affected [2].

Material damages were especially significant among historical buildings, independently of the scales. A notable number of vernacular houses (mostly built with earth techniques) was severely damaged or lost. Also, many masonry buildings, such as churches and other religious complexes, have been damaged. The existence of a National Catalogue of Historical Monuments, developed by the National Institute for Anthropology and History, allowed sketching an inventory of damaged cultural assets, the first of its kind in Mexico. From a total of 2,340 damaged buildings, 1,450 were labelled with moderate and severe damages. 61.4 % of the damaged buildings were located in Oaxaca, Puebla and Morelos [3]. These states correspond with the 3, 5 and 17 places in the national marginalisation index for 2015 [4], which is relevant for explaining the profound impact of this disaster in social and economic terms, representing additional challenges for the resilience process after the event.

Then, it becomes relevant to design wide-scale approaches for assessing the vulnerability of the existing building stock, preferably based on open-source and/or free tools, under the basis of relatively low financial and human investments. The goal of having easy-to-use and economic assessment means may permit to significatively prevent future loses and damages in the context of seismic events.

3 The Vulnerability Index Method

The concerns about the suitable assessment of the existing building stock fostered the development of simplified vulnerability assessment approaches, which are often based on the accumulated knowledge gathered from multiple observations on earthquakes and their effects. One of the most relevant approaches (due to its continuous refinement and enhancement since its origin in 1994) is the Vulnerability Index Method, originally developed in Italy by the National Group for the Defence from Earthquakes (*Gruppo Nazionale per la Difesa dai Terremoti* – GNDT). This method has been subsequently adapted to numerous contexts. It was designed for masonry structures, based on a set of assumptions related to the masonry material's mechanical characteristics, such as a brittle response in tension, a frictional response in shear and anisotropy. The analysis of a high volume of data correlating constructive features and levels of damage during seismic events permitted to recognise a set of parameters that result especially meaningful for conditioning the building's seismic performance. Those attributes have been gathered into a comprehensive survey datasheet [5].

The original approach was based on a set of eleven parameters. Each one of them is associated with four vulnerability classes related to the building's physical characteristics and their impact on the global vulnerability of the building. Besides, each parameter is related to a given weight that reflects the relative importance of the attribute in the whole set's context. The global index is given by the sum of the products of each parameter class value multiplied by a given weight [6], as shown in Eq. 1. The obtention of the normalised index (Eq. 2) permits to calculate the vulnerability index V (Eq. 3) and a corresponding mean damage grade (Eq. 4).

$$I_{vf}^{*} = \sum_{i=1}^{14} C_{vi} p_i \tag{1}$$

$$I_{vf} = \frac{100(I_{vf}^{*} + 100)}{675} \tag{2}$$

$$V = 0.0592 + 0.0057 \cdot I_{vf} \tag{3}$$

$$\mu_D = 2.51 + 2.5 \cdot \tanh\left(\frac{\mathrm{I} + 5.25 \cdot \mathrm{V} - 11.6}{\mathrm{Q}}\right) \tag{4}$$

In general terms, the calculation of the vulnerability index is also fed by a determined earthquake intensity I based on the EMS-98 scale [7] and a ductility value Q. It is possible to correlate some intervals of damage grades to a discrete set of five levels of damage, permitting to qualitatively describe the expectable effects that a determined earthquake would impose on the studied structure, such as the one provided by Aguado [8] (Table 1).

Table 1. Correlation between qualitative damage grades and mean damage grades

Discrete damage grades, D_k	**Damage factors, *DF***	**Mean damage grades, μ_p**
D_0 – No damage. No observed damage.	0.00	[0.00, 0.50]
D_1 – Slight damage. Presence of very localised and hairline cracking.	0.01	[0.50, 1.42]
D_2 – Moderate damage. Cracking around openings; localised detachment of wall coverings (plaster, tiles, etc.).s	0.10	[1.42, 2.50]
D_3 – Severe damage. Opening of large diagonal cracks; significant cracking of parapets; masonry walls may exhibit visible separation from diaphragms; generalised plaster detachment.	0.35	[2.50, 3.50]
D_4 – Very severe damage. Facade walls with large areas of openings have suffered extensive cracking. Partial collapse of the facade (shear cracking, disaggregation, etc.).	0.75	[3.50, 4.00]
D_5 – Destruction. Total in-plane or out-of-plane failure of the facade wall.	1.00	[4.00, 5.00]

Table 2. Set of parameters for the Vulnerability Index Method approach for façades

Parameters	**Class, C_{vi}**				**Weight P_i**	**Relative weight**
	A	B	C	D		
Group 1. Façade geometry, openings and interaction						16.7/100
FP1. Geometry of façade	0	5	20	50	0.50	
FP2. Maximum slenderness	0	5	20	50	0.50	
FP3. Area of openings	0	5	20	50	0.50	
FP4. Misalignment of openings	0	5	20	50	0.50	
FP5. Interaction between continuous façades	0	5	20	50	0.25	
Group 2. Masonry materials and conservation						31.5/100
FP6. Quality of materials	0	5	20	50	2.00	
FP7. State of conservation	0	5	20	50	2.00	
FP8. Replacement of original flooring system	0	5	20	50	0.25	
Group 3. Connection efficiency to other structural elements						33.3/100
FP9. Connection to orthogonal walls	0	5	20	50	2.00	
FP10. Connection to horizontal diaphragms	0	5	20	50	0.50	
FP11. Impulsive nature of the roofing system	0	5	20	50	2.00	
Group 4. Conservation status and other elements						18.5/100
FP12. Elements connected to the façade	0	5	20	50	0.50	
FP13. Improving elements	0	5	20	50	-2.00	

Proposals like those presented by Ferreira, Maio and Vicente [9, 10] have increased the parameters up to fourteen relevant characteristics to be taken into account, providing a calibrated set of weights as well. However, these methods present relevant limitations whenever, for example, it is impossible to acquire information regarding the internal organisation and conFigure uration of the constructions. In fact, information is often limited to the external façades of the buildings. These limitations were part of the reason behind the development of a Vulnerability Index Method specifically tailored to assess the seismic vulnerability of these elements by evaluating a set of thirteen parameters primarily obtained from façades observation. The detailed explanation of the parameters and the circumstances that affect their grading can be found in Aguado, 2017 [11].

4 Towards a workflow for the Vulnerability Index Method implementation

Each building can be associated with a dataset of values that can be used to obtain its vulnerability index; hence it is possible to build a database for saving the attributes for a comprehensive set of constructions. Given that buildings are robustly associated with a physical location, the implementation of a database through a Geographical Information System (GIS) is suitable. The distribution of this database through cloud services and the remote access to it would permit it to manage it from multiple devices, providing multiple advantages, such as collaborative work. Furthermore, the use of open-source and free distributed tools might enable to apply this workflow in multiple cases of study. In the context of free-software, QGIS is one of the most relevant tools devoted to GIS databases creation and management. This software is offered for a broad set of operative systems and permits to easily add functional complements developed on C++ and Python languages, which may be freely distributed as well. Some complements also permit the interoperability between the QGIS software and cloud services, such as Mergin. Mergin provides multiple services, including hosting QGIS files in a devoted cloud freely. A project hosted in the Mergin cloud can be accessed and edited by multiple users. Furthermore, it is possible to access and edit the projects from portable devices using a mobile application, Input app. Together, QGIS, Mergin and Input represent three compatible platforms for covering a workflow for creating, managing, hosting and accessing GIS databases (Figure 1).

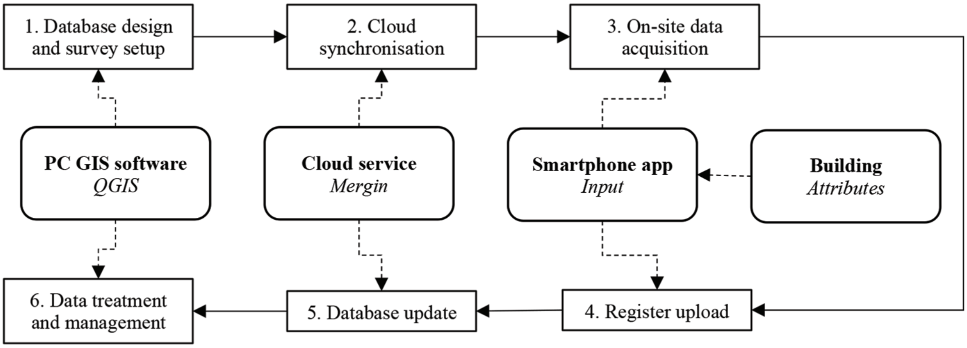


Figure 1. Software workflow and interoperability diagram

5 Materials and methods

The case study will be the city of Atlixco, Puebla, in the context of the September 19th, 2017, earthquake, an M_W = 7.1 event that caused severe damages in multiple settlements throughout the country, particularly in Puebla, Morelos, Oaxaca, Guerrero and Mexico City [12]. Atlixco has been selected as a case study due to its relative proximity to the epicentre (ca. 40km) and the existence of a vast corpus of catalogued historical monuments. Furthermore, Atlixco is one of the legally recognised Zones of Historical Monuments (Zona de Monumentos Históricos), which is an official designation for settlements and regions with relevant densities of historical monuments [13].

5.1 Experimental data

The seismic intensity value considered in this study was obtained from an intensities map provided by the United States Geological Survey (M 7.1 – 1 km E of Ayutla, Mexico, Interactive map https://earthquake.usgs.gov/earthquakes/eventpage/us2000ar20/map?historic-seismicity = true&shakemap-intensity = false) using the Modified Mercalli Intensity scale (MMI). These maps place Atlixco between the curves corresponding to MMI values of 7 and 7.5. For the present analysis, it was adopted a value of 7.5. The ductility of constructions is based on the table 4.2.3 of the Complementary Technical Code for Seismic Design of the Building Code for the Federal District -*Normas Técnicas Complementarias para diseño por sismo - Reglamento de Construcciones para la Ciudad de México* [14], which is widely used as a national standard for constructions. This table establishes a ductility value Q = 1.0 for unconfined or unreinforced masonry, regardless of the units' type (bricks or natural stones).

For this analysis, a set of nine constructions was selected taking into account the following criteria: to be clearly visible before and after the 2017 earthquake, to be catalogued in the National Catalogue for Historical Monuments (i.e., to be officially recognised as a historical asset) and to be a masonry construction. It was also considered that only constructions that appear in pre-event images in public databases (such as Google Maps) were selected, overcoming this way eventual lack of information due to the collapse or demolition of some buildings.

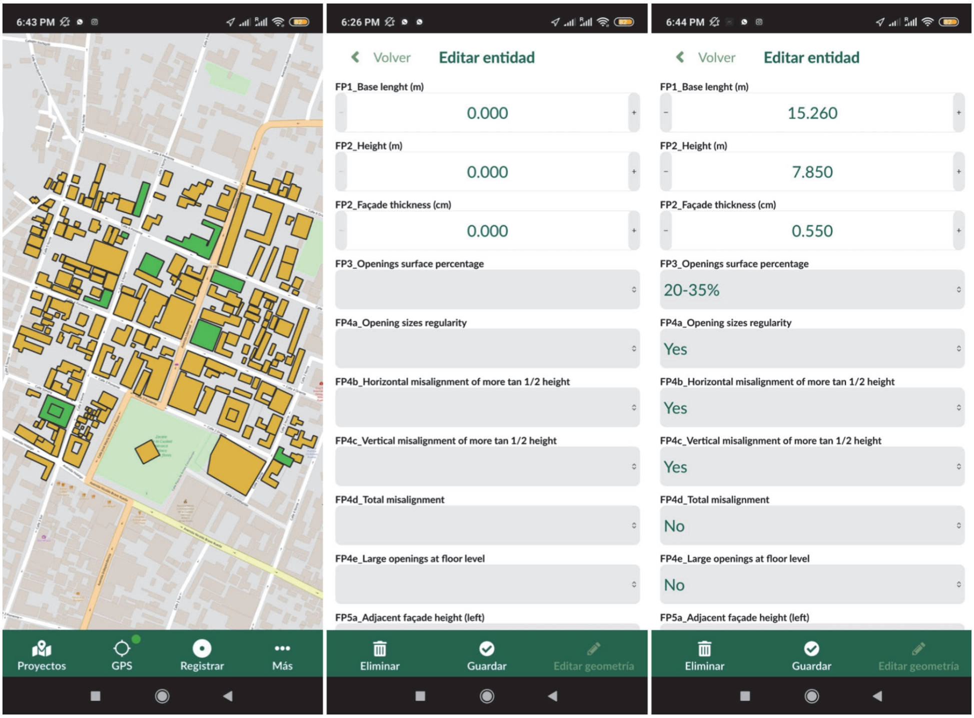
5.2 Data acquisition

A set of nine buildings located in the historical centre was selected and tagged using the National Catalogue of Monuments identification code. A base map was created in QGIS (Version 3.12 București) using the Open Street Maps public database as a primary source for obtaining the representative polygons of the constructions. The set of samples was isolated in an independent layer, in which the queries regarding the survey were encoded. This survey layer was set considering all the attributes and their corresponding conditions for assigning a determinate grade. Qualitative properties were programmed as Value Map variables, permitting to choose a given condition in a closed set of options. Furthermore, closed conditionals are programmed as simple Yes/No variables.

The project file was synchronised with the cloud service Mergin through a QGIS plugin available for the purpose, which permitted to provide access from mobile devices. The free app Input (version 0.7.7) was used on an Android 10.0 based smartphone. This app allows access to the QGIS project and to input the data gathered on-site directly into the various layers that compose the project (Figure 2).

There were a few cases where, due to the extensive damages imposed by the earthquake, the buildings were demolished and, therefore, information was not available. In these cases, the respective survey sheets were fulfilled resorting to pre-event photographs, namely those in Google Maps database.

The information gathered was synchronised with the cloud service and downloaded and opened in the QGIS desktop application (Figure 3), permitting to treat and analyse the data and export the entire database in various formats. In this case, for example, data were exported in .csv, which allowed computing each parameter's vulnerability class in a conventional MS Excel spreadsheet. However, if preferred, such arithmetic calculations could also be done directly inside QGIS.



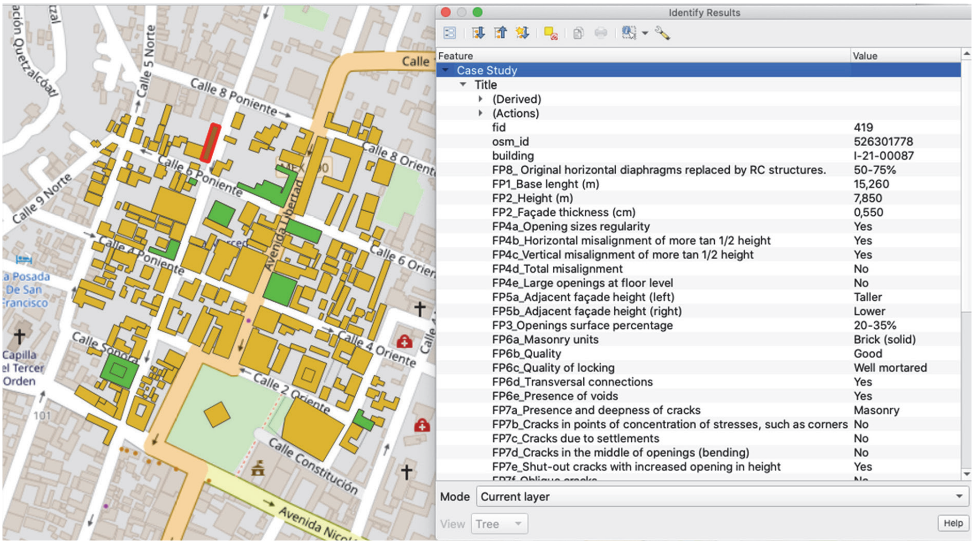
Editar entidad

FP1_Base lenght (m): 0.000
FP2_Height (m): 0.000
FP2_Façade thickness (cm): 0.000
FP3_Openings surface percentage:
FP4a_Opening sizes regularity:
FP4b_Horizontal misalignment of more tan 1/2 height:
FP4c_Vertical misalignment of more tan 1/2 height:
FP4d_Total misalignment:
FP4e_Large openings at floor level:
FP5a_Adjacent façade height (left):

Editar entidad

FP1_Base lenght (m): 15.260
FP2_Height (m): 7.850
FP2_Façade thickness (cm): 0.550
FP3_Openings surface percentage: 20-35%
FP4a_Opening sizes regularity: Yes
FP4b_Horizontal misalignment of more tan 1/2 height: Yes
FP4c_Vertical misalignment of more tan 1/2 height: Yes
FP4d_Total misalignment: No
FP4e_Large openings at floor level: No
FP5a_Adjacent façade height (left):

Figure 2. Screenshots of the survey implemented in the app Input over an Android platform



Feature	Value
Case Study	
Title	
(Derived)	
(Actions)	
fid	419
osm_id	526301778
building	I-21-00087
FP8_ Original horizontal diaphragms replaced by RC structures.	50-75%
FP1_Base lenght (m)	15,260
FP2_Height (m)	7,850
FP2_Façade thickness (cm)	0,550
FP4a_Opening sizes regularity	Yes
FP4b_Horizontal misalignment of more tan 1/2 height	Yes
FP4c_Vertical misalignment of more tan 1/2 height	Yes
FP4d_Total misalignment	No
FP4e_Large openings at floor level	No
FP5a_Adjacent façade height (left)	Taller
FP5b_Adjacent façade height (right)	Lower
FP3_Openings surface percentage	20-35%
FP6a_Masonry units	Brick (solid)
FP6b_Quality	Good
FP6c_Quality of locking	Well mortared
FP6d_Transversal connections	Yes
FP6e_Presence of voids	Yes
FP7a_Presence and deepness of cracks	Masonry
FP7b_Cracks in points of concentration of stresses, such as corners	No
FP7c_Cracks due to settlements	No
FP7d_Cracks in the middle of openings (bending)	No
FP7e_Shut-out cracks with increased opening in height	Yes

Figure 3. Screenshot of the QGIS interface, showing an example of a set of attributes

6. Results and discussion

The workflow permitted the satisfactory capture and storage of the information required for grading the attributes needed. Nevertheless, numerous circumstances did not allow to complete the survey without interruptions, such as the social distancing limitations imposed by the current pandemic situation and the reduced schedule for services and commerce. However, the capacity for partially fulfil and synchronise the survey permitted to easily continue the field works even after an interruption. When a survey suffered no interruptions, no more than ten minutes were necessary for completing the data acquisition, completing the set in just one journey. The data obtained on-site (Table 3) can then be processed to obtain the vulnerability class associated to each of the parameters that compose the vulnerability index method.

Table 3. Distribution of the vulnerability classes assigned to each parameter

National Catalogue of Monuments key		I-21-00087	I-21-00083	I-21-00086	I-21-00066	I-21-00024	I-21-00107	I-21-00079	I-21-00078	I-21-00121
FP1	Geometry of façade	A (0)	A (0)	A (0)	A (0)	A (0)	A (0)	B (5)	B (5)	C (20)
FP2	Maximum slenderness	A (0)	A (0)	A (0)	B (5)	B (5)	A (0)	B (5)	B (5)	B (5)
FP3	Area of openings	A (0)	B (5)	A (0)	C (20)	B (5)	B (5)	B (5)	B (5)	B (5)
FP4	Misalignment of openings	A (0)	B (5)	D (50)	A (0)	D (50)	A (0)	D (50)	A (0)	B (5)
FP5	Interaction between cont. façades	C (20)	D (50)	D (50)	D (50)	D (50)	D (50)	D (50)	C (20)	D (50)
FP6	Quality of materials	B (5)	C (20)	D (50)	D (50)	D (50)	B (5)	D (50)	B (5)	D (50)
FP7	State of conservation	B (5)	B (5)	C (20)	C (20)	D (50)	A (0)	B (5)	A (0)	B (5)
FP8	Flooring replacement	B (5)	A (0)	A (0)	D (50)	D (50)	A (0)	A (0)	A (0)	D (50)
FP9	Connection to orthogonal walls	C (20)	C (20)	C (20)	C (20)	D (50)	B (5)	C (20)	B (5)	C (20)
FP10	Connection to horizontal diaphragms	C (20)	C (20)	C (20)	C (20)	D (50)	C (20)	C (20)	A (0)	C (20)
FP11	Impulsive nature of roofing system	B (5)	B (5)	C (20)	C (20)	D (50)	B (5)	C (20)	B (5)	C (20)
FP12	Elements connected to the façade	A (0)	A (0)	A (0)	A (0)	D (50)	A (0)	A (0)	A (0)	B (5)
FP13	Improving elements	A (0)	A (0)	A (0)	A (0)	A (0)	A (0)	A (0)	A (0)	A (0)

Once the vulnerability classes are assigned, it is possible to compute each building's vulnerability index and, from it, the corresponding mean damage grades. Finally, the mean damage grades were compared to the observed post-event damage, allowing to verify the accuracy of the vulnerability index approach for this building typology.
As can be observed in Table 4, there is a good fitting between the predicted and values. In fact, only one out the nine buildings analysed resulted in a discrete damage grade different from that observed on-site after the earthquake. However, the tendencies are clear and coherent through the whole set.

Table 4. Vulnerability index method results

Results by building		I-21-00087	I-21-00083	I-21-00086	I-21-00066	I-21-00024	I-21-00107	I-21-00079	I-21-00078	I-21-00121
	Preliminar Vulnerability Index	86.25	127.50	267.50	267.50	505.00	55.00	245.00	42.50	245.00
	Normalised Vulnerability Index	27.59	33.70	54.44	54.44	89.63	22.96	51.11	21.11	51.11
	Vulnerability Index	0.75	0.78	0.90	0.90	1.10	0.72	0.88	0.71	0.88
	Mean damage grade	2.10	2.55	3.92	3.92	4.85	1.77	3.74	1.65	3.74
	Expected discrete damage grade	D_2	D_3	D_4	D_4	D_5	D_2	D_4	D_2	D_4
	Observed after 2017 Earthquakes	d_2	d_3	d_4	d_5	d_5	d_2	d_4	d_2	d_4

7. Conclusions

The present experiment permitted to demonstrate the suitability and robustness of a workflow for applying the Vulnerability Index Method approach through the integration of three open-source software platforms, enabling to distribute the entire workflow on suitable tools for office and/or remote work (such as PC terminal), cloud-storage services and mobile devices for field data acquisition.

The fieldwork procedure was completed fast, permitting to collect data from a significant number of buildings with a relatively small amount of material and human resources. Besides the on-site acquisition, this methodology could also be applied using data extracted from secondary sources, such as 3D models or remote imagery obtained by drones. Furthermore, the capacity for sharing a project in multiple devices from the same cloud services allows to design and implement collaborative work for covering wide areas and samples, permitting to feed accumulative, economic and collaborative databases.

The results obtained from the Vulnerability Index Method approach exhibited a good correspondence with the real damages imposed by the September 2017 earthquake on the structures analysed in this work, which seems to prove the suitability of the method to assess the seismic vulnerability of traditional Mexican masonry buildings. If that can be confirmed with further data, this approach would be a valuable tool for supporting urban planning and seismic risk mitigation decision making. Among other advantages, this approach is of easy implementation and entirely based on free and open-source software.

Acknowledgements

This research was funded by the Portuguese Foundation for Science and Technology (FCT) through the grant number PD/BD/150385/2019.

References

[1] Instituto Nacional del Suelo Sustentable, A dos meses del sismo del 7 de septiembre se han entregado 62 mil tarjetas para la reconstrucción de Oaxaca: Rosario Robles, 2017. [Online]. Available: https://www.gob.mx/insus/prensa/a-dos-meses-del-sismo-del-7-de-septiembre-se-han-entregado-62-mil-tarjetas-para-la-reconstruccion-de-oaxaca-rosario-robles-133281?idiom = es.

[2] Alberto, Y., Otsubo, M., Kyokawa, H., Kiyota, T., Towhata, I.: Reconnaissance of the 2017 Puebla, Mexico earthquake, Soils Found., vol. 58, no. 5, pp. 1073–1092, 2018.

[3] C. San Juan, R. Casanova, and C. Álvarez, "La tierra se sacudía como queriendo pelear," pp. 89–93, 2017.

[4] Consejo Nacional de Población CONAPO, Anexo A Índice de marginación por entidad federativa, 2010, Índice Marginación Por Entid. Fed. Y Munic. 2010, pp. 56–61, 2010.

[5] Lourenco, L., Vicente, R., Ferreira, T.M., Maio, R. 2014): O papel da vulnerabilidade sísmica na mitigação: do risco sísmico de núcleos urbanos antigos, Multidimensão e Territ. risco, no. 1994, pp. 199–203.

[6] Calvi, G.M., Pinho, R., Magenes, G., Bommer, J.J., Restrepo-Velez, L.F., Crowley, H. (2006): Restrepo-Vélez, and H. Crowley, Development of seismic vulnerability assessment methodologies over the past 30 years, ISET J. Earthq. Technol., vol. 43, no. 3, pp. 75–104.

[7] Centre Europèen de Géodynamique et de Séismologie, L'Échelle Macrosismique Européenne (EMS-98), vol. 15. Luxembourg: Joseph Beffort, Helfent-Bertrange, 1998.

[8] Aguado, J.L.P., Ferreira, T.M., Lourenco, P.B. (2018): The Use of a Large-Scale Seismic Vulnerability Assessment Approach for Masonry Façade Walls as an Effective Tool for Evaluating, Managing and Mitigating Seismic Risk in Historical Centers, Int. J. Archit. Herit., vol. 12, no. 7–8, pp. 1259–1275.

[9] Ferreira, T.M., Maio, R., Vicente, R. (2017): Analysis of the impact of large scale seismic retrofitting strategies through the application of a vulnerability-based approach on traditional masonry buildings" Earthq. Eng. Eng. Vib., vol. 16, no. 2, pp. 329–348.

[10] Maio, R., Estevao, J. M. C., Ferreira, T.M., Vicente, R. (2020): Casting a new light on the seismic risk assessment of stone masonry buildings located within historic centres, Structures, vol. 25, no. February, pp. 578–592.

[11] Palomino Aguado, J.L. (2017): Vulnerability Assessment as a Tool to Mitigate and Manage Seismic Risk in Old Urban Areas, University of Minho.

[12] Galvis, F., Miranda, E., Heresi, P., Davalos, H., Silos, J.R. (2017): Silos, Preliminary Statistics of Collapsed Buildings in Mexico City in Puebla-Morelos Earthquake, Tech. Rep., no. October, p. 17.

[13] Estados Unidos Mexicanos - Presidencia de la República, DECRETO por el que se declara una zona de Monumentos Históricos en la ciudad de Atlixco, Pue., con el perímetro, características y condiciones a que se refiere este decreto, Diario Oficial de la Federación, México, 27-May-1988.

[14] Administración Pública de la Ciudad de México, Acuerdo por el que se actualizan las Normas Técnicas Complementarias para diseño por sismo con comentarios, Gaceta Oficial de la Ciudad de México, no. 361, 2020.