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TOWARDS AN INTEGRATED VULNERABILITY-BASED APPROACH FOR EVALUATING, MANAGING AND MITIGATING EARTHQUAKE RISK IN URBAN AREAS

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Research insights

This research is aimed to propose a characterisation model for assessing the seismic vulnerability of historical cities.

The main topics to be explored are:

- a) The characterisation of the historical city from the seismic-vulnerability point of view.
- b) Characterisation of the seismic vulnerability of historical constructions.
- c) Suitability and pertinency of multiple data-acquisition strategies.
- d) Vulnerability-oriented data management by the means of GIS platforms.
- e) Risk analysis based on urban vulnerability GIS DATABASE.



Schematic workflow

The original workflow has suffered minor changes from its initial concept. The project is conceived as a workflow with five major axis (in blue) linked by a series of research questions (in gray), existing theoretical frameworks and definitions (white, pointed lines) and processes to be designed and implemented (white, full lines). The organic growth and enrichment of this workflow has defined the tasks of the research.



Task 1. State-of-the-Art

As the first task of the project, the literature review permitted to have an insight on the suitability of assessing the Historic Urban Landscapes by the means of the integration of multiple tools, such as GIS GIS DATABASE and BIM or HBIM models. This work offered a first insight on the research questions, supporting the establishment of the project axis.



Task 1. State-of-the-Art

This literature review was a major part of the Thesis Project defence (September, 2020). This part of the research was further condensed and consolidated in a journal paper, stablishing a suitable and preliminary structure.



Rafael Ramírez Eudave & Tiago Miguel Ferreira (2020): On the suitability of a unified GIS-BIM-HBIM framework for cataloguing and assessing vulnerability in Historic Urban Landscapes: a critical review, International Journal of Geographical Information Science, DOI: 10.1080/13658816.2020.1844208

Task 2. Characterisation of Risk and approach to Risk Analysis

Some valuable tools were analysed and discussed in the context of the INFRRISK curricular unit «Reliability and Risk Analysis». In particular, the use of Failure Tree Analysis, Event Tree Analysis and Failure Mode and Event Analysis approaches were considered as potentially applicable for this research.



Task 2. Characterisation of Risk and approach to Risk Analysis

Even if the final assignment of the Curricular Unit was not focused on the seismic vulnerability of historical constructions, it permitted to analyse a different phenomenon in Mexican context, that of the evacuation scenarios due to the activity of the Popocatépetl volcano.

The application of the FTA, ETA and FMEA approaches permitted to produce a journal paper in which the territorial analysis permitted to anticipate more opportunities of applicability, such as in the present research.



RamírezEudave,R.; Ferreira, T.M. Towards a Semi-Quantitative Approach for Assessing Evacuation Scenarios in the Context of Popocatépetl Volcano, México—The Case of San Pedro Tlalmimilulpan. GeoHazards 2021, 2, 1–16. https://doi.org/10.3390/ geohazards2010001

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Task 3. Semantic description of the Historic Urban Landscape

The third stage of the project consisted in the review of literature devoted to the description of the Historic Urban Landscape and historical constructions. This process permitted to identify valuable sets of semantic descriptors that would later be included in the survey model.



Task 3. Semantic description of the Historic Urban Landscape

The concept of the Historic Urban Landscape and its implications lead to a theoretical analysis devoted to propose how to systematically characterise the urban entities, namely in the context of GIS DATABASE. This approach tries to conciliate the numerous interests and specialised views on the historical city. This analysis and an example of application in the city of Guimarães were presented in a journal paper.



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Task 4. First insights on survey methods: on-site survey

Besides the evidence of a potential GIS-BIM-HBIM integration in Task 1, the possibility of enhancing and enriching field-survey campaigns was analysed. Therefore, a workflow based on the integration of GIS DATABASE, cloud-based storage and collaborative work on portable devices was successfully tested, adding a valuable tool for data acquisition.



Task 4. First insights on survey methods: on-site survey

An example of the use of this workflow and a discussion on its advantages and limitations was presented in the 1st Croatian Conference on Earthquake Engineering.

In order to demonstrate the suitability of the workflow in the context of a vulnerability-oriented survey, the Vulnerability Index Method was selected. This parameter-based method, originally designed and applied in Italy, departs from a selection of parameters that influence the seismic behaviour of masonry constructions.

Hence, an experimental campaign for acquiring these parameters from nine constructions damaged during the 2017 Earthquake in Atlixco (Puebla, México) was carried-out.



Rafael Ramírez Eudave & Tiago Miguel Ferreira. Proposal for a suitable workflow for assessing the seismic vulnerability of historical buildings. Atlixco (Puebla, México) as a case study. Proceedings of 1st Croatian Conference on Earthquake Engineering, 1CroCEE. Zagreb, Croatia - March 22nd to 24th, 2021. DOI: https://doi.org/10.5592/CO/1CroCEE.2021.22

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Task 5. The suitability of the INAH datasheet for assessing seismic vulnerability.

The existence of the National Catalogue of Historical Monuments permitted to explore the suitability of the Vulnerability Index Method approach in Mexican buildings. The consequences of the September 2017 Earthquake in Puebla were analysed, by comparing the correspondence between the real and forecasted damages in nine historical constructions of the city.



Task 5. The suitability of the INAH datasheet for assessing seismic vulnerability.

Parameters		С	lass C_{v_i}	i)	Weight)	Relative weight		
	А	В	С	D				
Group 1. Structural building system						50/100		
BP1. Type of the resisting system	0	5	20	50	2.50			
BP2. Quality of the resisting system	0	5	20	50	2.50			
BP3. Conventional strength	0	5	20	50	1.00			
BP4. Maximum distance between the walls	0	5	20	50	0.50			
BP5. Number of floors	0	5	20	50	0.50			
BP6. Location and soil condition	0	5	20	50	0.50			
Group 2. Irregularities and interaction						20/100		
BP7. Aggregate position and interaction	0	5	20	50	1.50			
BP8. Plan configuration	0	5	20	50	0.50			
BP9. Height regularity	0	5	20	50	0.50			
BP10. Wall façade openings and alignment	0	5	20	50	0.50			
Group 3. Floor slabs and roofs						18/100		
BP11. Horizontal diaphragms	0	5	20	50	0.75			
BP12. Roofing system	0	5	20	50	2.00			
Group 4. Conservation status and other elements						12/100		
BP13. Fragilities and conservation status	0	5	20	50	1.00			
BP14. Non-structural elements	0	5	20	50	0.75			

Discrete damage grades, \boldsymbol{D}_k

 $D_0 - No$ damage. No observed damage.

D₁ – Slight damage. Presence of very localised and hairline cracking.

D₂ – Moderate damage. Cracking around openings; localised detachment of wall coverings (plaster, tiles, etc.).

D₃ – Severe damage. Opening of large diagonal cracks; significant cracking of parapets; masonry walls may exhibit visible separation from diaphragms; generalised plaster detachment.

D₄ – Very severe damage. Facade walls with large areas of openings have suffered extensive cracking. Partial collapse of the facade (shear cracking, disaggregation, etc.).

D₅ – Destruction. Total in-plane or out-of-plane failure of the facade wall.

Task 5. The suitability of the INAH datasheet for assessing seismic vulnerability.

Despite the limitations imposed by the size of the sample, the results of this analysis supported the suitability of using the Vulnerability Index Method approach for assessing Mexican constructions. Furthermore, this approach is compatible with the National Catalogue of Historical Monuments, since most of the parameters are already considered in its survey model. The comparative analysis between the Vulnerability Index Method and the Catalogue is included in a recently published journal paper. Besides, this document includes and discusses the results of the application on the city of Atlixco.



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The ongoing tasks are devoted to the analysis of a recently found source of data that includes the pre-event state and the damages found in a total of 85 historical constructions in Atlixco, Puebla. The current state of the research includes the refinement of the Vulnerability Index Method for its application in Mexican buildings and the potential outcomes that the vulnerability assessments can offer. These tasks will enrich the strategies for data management as well.



- a) Adaptation and calibration the Vulnerability Index Method based on the extended sample of Atlixco.
- b) Uncertainty analysis and uncertainty management.
- c) Potential correlations between the full-building and façade-based approaches.
- d) Setup and test of a dedicated database.





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GRADING DISTIBUTION AMONG PARAMETERS - FULL BUILDING APPROACH

Future tasks: GIS-BIM-HBIM and Remote Sensing implementation

The future tasks are focused on the analysis and implementation of the GIS-BIM-HBIM integration for obtaining vulnerability-based descriptions from existing models. Furthermore, the data acquisition based on remote sensing tools will be also studied and put in practise. The design of the database will be done according to the results and knowledge generated in the present stage of the research. The potential outcomes of the database will be stablished in order to design the urban-scale vulnerability assessment.



Future tasks: Implementation of the workflow in a case of study

The research is expected to reach a full-scale test in a real urban centre as final stage. This case of study would reflect the suitability and interoperability of all the stages of the workflow, permitting to provide a valuable risk analysis and a general insight of the most important mitigation measures. This example of application would permit to identify some potential limitations and opportunities for the entire workflow as a systematised procedure.



Schedule

		1st Year Trimester								ear ster	3st Year Trimester										
Task	Task description	T1		T2	2	T3		T4	T1		T2		T3	T4	T1		T2		T3		T4
Т0	State-of-the-art and literature review																				
Paper	On the suitability of a unified GIS-BIM-HBIM framework for cataloging and assessing vulnerability in historic urban landscapes: A critical review.																				
Subm.	June 4th, 2020									_											
T1	Design of semantic characterisation models																				
Paper	HUL entities semantic characterisation oriented to vulnerability assessment.																				
Subm.	February, 2021 (expected)																				
T2	Design of survey methods																				
Paper	HUL Vulnerability-oriented HUL surveying tools.																				
Subm.	July, 2021 (expected)																				
Т3	Design of vulnerability assessment frameworks																				
Paper	HUL Multi-level seismic vulnerability assessment for HUL entities.																				
Subm.	November, 2021 (expected)																				
Т4	Design of an unified data management framework																				
Paper	Unified framework for HUL seismic vulnerability assessment.																				
Subm.	March, 2022 (expected)																				
Τ5	Integration and application																				
Paper	Seismic vulnerability assessment for the Historic Urban Centre of Tomar: a methodological approach.																				
Subm.	July, 2022 (expected)																				

Conclusions

- The present research project is aimed to propose a suitable and comprehensive workflow for assessing the seismic vulnerability of historical urban areas.
- At the present moment, the completed tasks comprises:
 - A literature review that supports the general framework and its elements;
 - A review on strategies for risk assessment;
 - The definition of a strategy for the description of the HUL and the historical constructions;
 - A first insight on the suitability of GIS distributed tools for data acquisition and;
 - A first insight on the use of the Mexican catalogue and the Vulnerability Index Method for large-scale seismic vulnerability assessment of constructions.
- The current stage of the research is devoted to the analysis of a set of 85 constructions for adapting the Vulnerability Index Method for Mexican constructions.
- The future works include the implementation of GIS-BIM-HBIM integration, urban-scale vulnerability assessments and at least one example of application.
- At the present moment, all the tasks have been carried-out according to the Schedule.

Thank you

