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AUTOMATED ALGORITHM FOR SPATIAL CHARACTERISATION OF BUILDINGS WITHIN URBAN BLOCKS

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Abstract

Seismic exposure of buildings characterises the existing structures within a specific area to ascertain the regions structural reality. This assessment of seismic exposure is essential for estimating the response of these buildings to a seismic event, enhancing urban planning, and reducing seismic risk in the area. The new geospatial methodologies lead to the increase of spatial resolution of seismic exposure analysis, allowing for the collection of geospatial data for each individual building, although fieldwork is still necessary to acquire a complete sample of relevant attributes to calibrate and validate models.
This research is framed in a study to apply geospatial techniques into seismic exposure assessments to automate the extraction of various building attributes. Here we present the automatization of the attribute "building's position within a block of buildings. Five possible positions have been identified concerning their surroundings: confined (with buildings on both sides), terminal (with buildings on only one side), corner (with a building on one side and behind its

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main façade), isolated (with no buildings around it) and torque (a variation of confined or corner positions).
The acquisition of this data for each building individually, without the need for field surveys and through automated processes, represents a significant advancement in seismic risk studies for urban areas. Identifying these attributes that influence a structure's response to seismic activity will enhance the accuracy of seismic risk assessments that consider them, compared to studies that disregard such effects.

Keywords: seismic exposure, seismic risk, relative position in an aggregate, building foot-prints, automation, phyton packages

1 INTRODUCTION

From 1900 to 2019, earthquakes were responsible for approximately 2.6 million 43 deaths worldwide, ranking as the third most significant cause of mortality among natural 44 disaster events, after floods and droughts. In terms of economic losses, earthquakes rank 45 second, with total damages reaching $828 billion, surpassed only by storms, which ac-46 counted for $1,447 billion in losses [1].

Seismic risk assessments that measure and estimate potential losses in the event of a major earthquake are essential for environmental preparedness and prevention, as these events cannot be predicted in terms of time or location. Therefore, it is crucial to have a city, infrastructure, and buildings that are designed and engineered to be resilient to seismic events, as well as a population that is educated and prepared to respond to such emergencies.

Seismic risk studies are based on three key components: hazard, exposure and vulnerability [2]. Seismic hazard represents the probability of exceeding a given level of ground shaking intensity at a specific location within a defined time period. Seismic exposure encompasses the inventory and characterisation of elements or assets -such as population, buildings, and infrastructure- situated within a hazard-prone area and susceptible to potential losses resulting from earthquake events [3]. Vulnerability integrates these factors by evaluating the anticipated performance and structural response of exposed assets when subjected to seismic activity.

The seismic exposure of buildings characterises the structures within the study area to determine their properties and current condition. This assessment of seismic exposure is one of the initial steps in a comprehensive evaluation of the risk that a seismic event poses to a population. The evaluation of seismic exposure is conducted by identifying the principal structural characteristics that may influence a building’s response to an earthquake.

In the present study, the seismic exposure assessment methodology proposed by the Global Earthquake Model (GEM) [4] as been applied. This methodology characterises structures based on 13 attributes, which are grouped into several categories and classified at different levels of detail depending on the specific attribute [5]. The attributes and their corresponding levels are presented in Table 1.

Group of attributes	#	Attribute	Attribute levels
Structural system	1	Direction	Direction of the building
	2	Material of the lateral load-resisting system	Material type (level 1) Material technology (level 2) Material Properties (Level 3)
	3	Lateral load-resisting system	Type of the lateral load-resisting system (level 1) System ductility (level 2)
Building Information	4	Height	Height
	5	Date of construction or retrofit	Construction completed (year)
	6	Occupancy	Building occupancy class - general (level 1) Building occupancy class - detail (level 2)
Exterior attributes	7	Building position within a block	Building position within an aggregate
	8	Shape of the building plan	Plan shape (footprint)
	9	Structural irregularity	Regular or irregular (level 1) Plan irregularity or vertical irregularity (level 2) Type of irregularity (level 3)

	10	Exterior walls	Exterior walls
Roof, floors, and foundation	11	Roof	Roof shape (level 1) Roof Covering Material (Level 2) Roof system material (level 3) Type of roof system (level 4) Roof connections (level 5)
	12	Floor	Material of the floor system (level 1) Floor system type (level 2) Floor connections (level 3)
	13	Foundation system	Foundation system

Table 1: Attributes and levels of the GEM taxonomy [5]

The traditional methodology has been based on conducting field surveys [6]. The data collected is then extrapolated to a larger scale, at the neighbourhood or district level, rather than for individual buildings, assigning a distribution of structures to each unit and specifying the percentage of structures belonging to each structural system class. However, as technology and geomatic techniques have advanced [7], their integration into field studies has also progressed.

Initially, georeferenced databases were used to enhance the efficiency of processing field survey data [8] [9]. In recent years, geomatic techniques have been increasingly incorporated into the extraction of specific attributes using various methodologies, such as Street View imagery [10], LiDAR point clouds [11] o UAV photogrammetry [12].

This study primarily focuses on the acquisition of the seventh attribute using geomatic techniques. This attribute refers to the position of a building within a block, which significantly influences the structural behaviour of a building during a seismic event. The Risk-UE project [13], conducted in 2003, already highlighted the importance of this attribute in determining a building's seismic response. Therefore, obtaining this attribute for each building within a given area can provide highly valuable information, enhancing the accuracy of seismic risk assessments and forecasts for the study region.

The objective of this research is to define a methodology for automatically determining a building's position within a block based on the building footprints in the study area.

2 METHODOLOGY

To determine the position within an aggregate, the analysis must begin with the footprints of the buildings in the study area. A high level of precision in these footprints is essential to improve the accuracy of the results. To establish whether two buildings are in contact, two criteria have been defined for identifying such connections:

- Having a separation of less than 5 cm between buildings.
- The contact with the adjacent building must account for at least 20% of the length of the side to be considered valid

Once the criteria for identifying contact between buildings have been defined, the positions to be identified in relation to the block are also outlined, following Figure 1, derived from the master's thesis by Josué Pillajo. [14]:

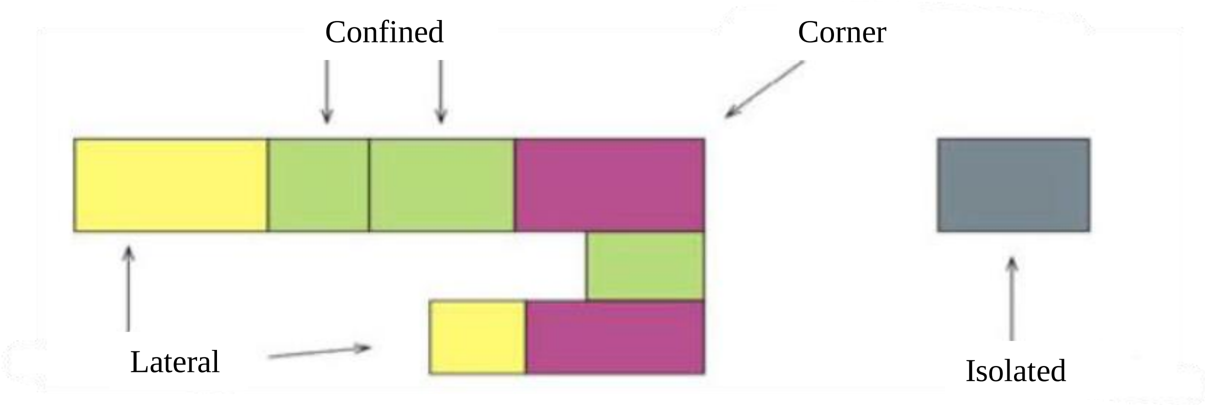

Figure 1: Relative positions to aggregate.

The different relative positions are the ones in the figure 1 and additionally one called “torque”. The classes are:

- Confined: touches on both lateral sides.
- Corner: touches at a corner.
- Lateral: touches on one side.
- Torque: high angular acceleration and class confined or corner.
- Isolated: no touching structures.

The methodology developed calculates "forces" that neighboring structures exert on the building, proportional to the contact area (length of touching footprints multiplied by building height) in the normal direction of the touching plane. Contact forces are calculated using the following process:

Firstly, the angular acceleration is calculated as:

$$Angular\ acceleration = \frac{momentum \cdot area}{inertia} \tag{1}$$

where momentum is calculated as:

$$Momentum = \sum(distance \cdot |force_i|) \tag{2}$$

Then is calculated the force, which is the magnitude of the resultant force acting on the footprint, normalized by the square root of the area:

$$Force = |\sum force_i| \tag{3}$$

After that, the confinement ratio is the proportion of total forces that are confined (counterbalanced by opposing forces) is calculated as:

$$Confinment\ ratio = \frac{\sum|force_i| - |\sum force_j|}{|\sum force_i|} \tag{4}$$

Finally, the angle is the normalized sum of the angles between individual forces and the resultant force:

$$Angle = \frac{\sum\left(|force_i| \cdot Angle\ (force_i, \sum force_j)\right)}{|\sum force_i|} \tag{5}$$

3 RESULTS

The proposed methodology has been developed into a Python library, available on GitHub [15]. This tool allows for the automatic calculation of the relative position of buildings, given georeferenced footprints in a compatible format. In this way, a transferable product has been created, which can be used by public administration technicians in their seismic risk assessments.

This methodology has been applied to a study area in the city of San José. The study area is shown in Figure 2:

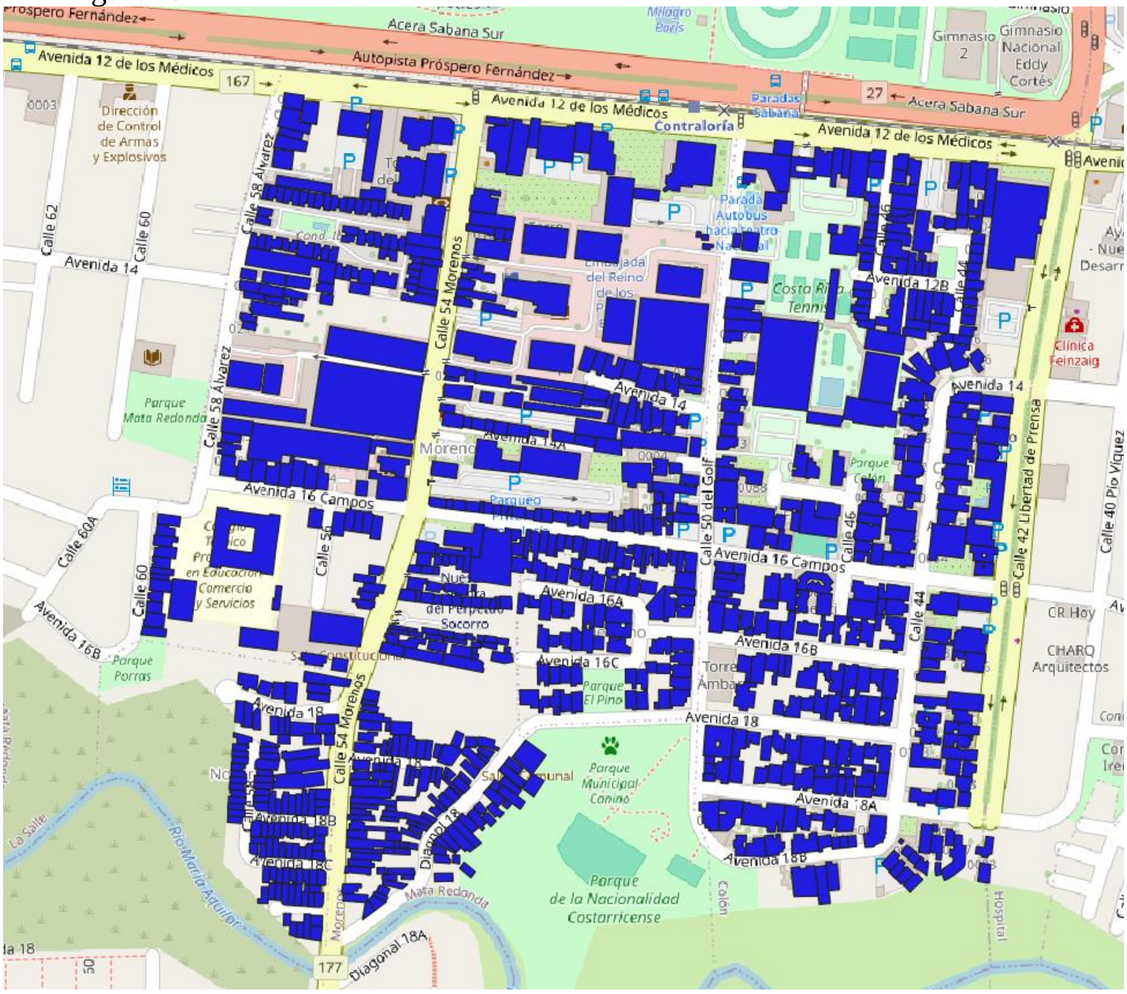

Figure 2: Study zone in San José, Costa Rica.

The footprints of the study area were manually digitised by trained students, with a maximum error margin of 20 cm, which is highly precise. The input images have a high spatial resolution, allowing for this level of accuracy. In cases where footprints with lower precision are available, the parameter in the code can be adjusted so that the calculations produce results consistent with the accuracy of the footprints.

The results obtained for this study area are shown below in Figure 3:

Figure 3: Buildings classified according to its position within an aggregate.

As shown in Figure 3, the larger isolated buildings in the north are well identified where the buildings density decreases. In the south and northwest, where residential buildings predominate, it can be observed that within aggregates and rows, the methodology correctly detects confined buildings, distinguishing them from those located at the edges.

According to the Risk-UE [13] study, the same building with different values for this modifier will exhibit different seismic behaviour under the same event. In that study, reinforced concrete buildings constructed under outdated regulations—or even without any regulations—tend to have low ductility, which, when combined with being part of an aggregate, negatively affects their seismic performance.

In the case of masonry buildings, regardless of their construction date, they generally perform better when confined within a block than when isolated. However, when located on a corner, their performance is penalised to the same extent as it improves when confined. Finally, buildings positioned at the end of a row exhibit the poorest seismic performance.

4 DISCUSION

The results of this methodology primarily depend on the accuracy of the building footprints, as the distances between buildings are usually very small and may even be imperceptible if the input image does not have sufficient spatial resolution. This is because the separation between structures may be small but still exist, and there may be elements that obscure the true distance between them. Therefore, the library developed in this project allows for the adjustment of the error margin used when digitizing the footprints, enabling the calculation to be refined based on the input data.

This procedure enables the automated calculation of the parameter for each building individually, proposing a methodology that improves the spatial resolution of this attribute in seismic exposure studies. The acquisition of this data for each building individually, without the need for field surveys and through automated processes, represents a significant advancement in seismic risk studies for urban areas.

The open access library allows for the integration of this methodology into studies conducted by local authorities who wish to include it in their seismic risk assessments. The resulting product can be used by technicians who are not specialists in programming but are capable of overseeing the process of obtaining seismic exposure attributes for the study area in question.

Having knowledge of these parameters for all buildings in the study area not only allows for a more precise estimation of seismic risk but also facilitates the implementation of preventive measures. This enables urban planning to be carried out with a comprehensive understanding of the city's actual conditions and the urban configurations associated with higher risk. Furthermore, it supports the development of structural rehabilitation plans by providing more detailed information on which buildings are most vulnerable and less prepared for a seismic event. Therefore, having tools that enhance the understanding of the area being prepared for an earthquake is of great value.

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