

Residential Building Stock Classification in North Macedonia: Adapting Existing Taxonomies to Local Characteristics

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Abstract

Accurate seismic risk assessment requires a consistent and representative characterization of the building stock and exposed population. This study presents a national-scale classification of the residential building stock in North Macedonia by adapting global building taxonomies to locally available data. Using data from the 2021 Population and Housing Census and the State Statistical Office, an exposure model was developed for all 80 municipalities, incorporating key parameters such as structural material, number of storeys, and construction period. A simplified taxonomy framework was established by comparing national data with the Global Earthquake Model (GEM) Building Taxonomy and the HAZUS methodology. Structural materials were mapped to corresponding taxonomy classes, while building height was derived from the number of storeys and grouped into low-, mid-, and high-rise categories. Construction periods were used as proxies for seismic design levels, enabling classification into pre-code, low-code, and modern-code buildings. The results indicate that reinforced concrete structures dominate the building stock and accommodate the majority of the population, particularly in buildings designed according to modern seismic codes. However, a significant portion of the population remains exposed to older, more vulnerable structures. The proposed framework enables consistent integration into seismic risk models and provides a basis for improved risk assessment and mitigation planning.

Keywords: Seismic risk, Building taxonomy, GEM, HAZUS, Exposure

1- INTRODUCTION

Seismic risk assessment is a fundamental component of disaster risk reduction, particularly in regions exposed to moderate to high seismic hazard. Reliable estimation of potential earthquake impacts depends not only on the characterization of seismic hazard but also on an accurate representation of the exposed elements, including buildings and population. Among these, the building stock plays a central role, as its structural characteristics largely determine the extent of physical damage, while population distribution influences the potential for human losses.

Exposure, defined as the inventory of elements at risk, is a critical input for seismic risk models. It encompasses both the physical attributes of buildings, such as structural material, height, and construction period and the spatial distribution of the population within these structures. Without a detailed and consistent description of exposure, even the most advanced hazard and vulnerability models cannot provide reliable risk estimates. Therefore, the development of robust exposure models is essential for supporting risk mitigation strategies, emergency planning, and policy-making.

In North Macedonia, several studies have contributed to the development of exposure and taxonomy models for seismic risk assessment. Initial efforts focused on establishing GIS-based building inventories and seismic safety databases at the municipal level, particularly within the Municipality of Karpoš, where detailed field surveys were conducted [1]. More recent research has extended these approaches to urban-scale seismic risk analyses in Skopje by integrating exposure models with urban development scenarios and probabilistic risk assessments [2]. Similar methodologies have also been applied in other Macedonian cities, including Strumica, combining cadastral information, field observations, and GEM-based classification procedures [3]. Existing studies are limited to specific municipalities and case-study areas, while a consistent and detailed exposure model covering the entire building stock of North Macedonia is still lacking. The development of such models is constrained by the limited availability of detailed building-level data [4], [5]. In addition, the diversity of construction practices, the presence of older buildings constructed without seismic design, and the coexistence of multiple structural typologies further complicate the classification of the building stock [6].

These challenges necessitate the development of simplified yet representative classification schemes that can capture the most relevant characteristics influencing seismic performance.

The building stock has been significantly influenced by historical events, regulatory changes, and evolving construction technologies. In particular, the 1963 Skopje earthquake [7] led to major revisions in seismic design practices and a shift toward reinforced concrete construction [8]. Consequently, the current building stock consists of a heterogeneous mix of structures with varying levels of seismic resistance, depending on their construction period and structural system.

This study aims to develop a comprehensive classification of the residential building stock in North Macedonia by adapting existing global taxonomies to locally available data and construction characteristics. Using data from the 2021 population census and the State Statistical Office, the study establishes a municipal-level exposure model that categorizes buildings according to structural material, height, and construction period, with explicit consideration of the applicable seismic design codes. By bridging the gap between global methodologies and local data constraints, this work contributes to improving the reliability of seismic risk assessments and supports the development of more effective risk mitigation and planning strategies.

2- BACKGROUND AND EXISTING TAXONOMIES

The classification of building stock is a fundamental step in seismic risk assessment, as it provides the basis for linking structural characteristics with expected seismic performance. Over the past decades, several global frameworks have been developed to standardize the description of buildings for exposure and vulnerability modeling.

One of the most comprehensive and widely adopted systems is the taxonomy developed by the Global Earthquake Model (GEM) Foundation. The GEM Building Taxonomy provides a modular and extensible framework for describing buildings using a set of attributes that capture key aspects of structural behavior. These include the primary structural system, construction material, height, lateral load-resisting mechanism, level of seismic design, and additional modifiers such as irregularities and construction quality [9]. The flexibility of this taxonomy allows it to be adapted to different regions while maintaining consistency in seismic risk modeling.

Another widely used methodology is HAZUS, developed by the Federal Emergency Management Agency (FEMA) [10]. HAZUS classifies buildings into predefined categories based on structural type, height class (low-, mid-, and high-rise), and design level (pre-code, low-code, moderate-code, and high-code). This approach is closely linked to vulnerability and loss estimation models and has been extensively applied in the United States and adapted for use in other regions.

Despite differences in structure and level of detail, these global taxonomies share a set of common classification parameters that are essential for seismic analysis. These typically include:

- **Structural system**, which defines the primary load-resisting mechanism (e.g., moment frames, shear walls, masonry walls);
- **Construction material**, such as reinforced concrete, masonry, steel, or timber;
- **Building height**, usually expressed in terms of the number of stories and grouped into low-, mid-, and high-rise categories;
- **Construction period or code level**, which reflects the seismic design provisions in effect at the time of construction and serves as a proxy for expected structural performance.

These parameters are critical because they directly influence the seismic response of buildings and are therefore central to both exposure and vulnerability modeling.

However, the direct application of global taxonomies in specific national contexts, such as North Macedonia, presents several challenges. First, **local construction practices** often differ from those assumed in global frameworks. For example, the widespread use of reinforced concrete frame systems with masonry infill, as well as variations in detailing and construction quality, may not be fully captured by standard taxonomy classes.

Additionally, **mixed construction types** are common, particularly in older buildings where different materials (e.g., stone and brick, or masonry and reinforced concrete) are combined within the same structure. This hybridity challenges the assignment of a single structural class and may lead to misrepresentation of seismic behavior if not properly addressed.

Finally, the **evolution of seismic design codes** in the country further complicates the classification process. Changes in regulations, particularly following major seismic events such as the 1963 Skopje earthquake, have resulted in a building stock with varying levels of seismic resistance. Mapping construction periods to code levels requires careful interpretation of historical regulatory frameworks and their practical implementation.

These limitations highlight the need for adapting global classification systems to local conditions. While frameworks such as GEM and HAZUS provide a robust conceptual basis, their effective use depends on the ability to incorporate locally relevant building characteristics and data constraints.

Therefore, this study adopts a hybrid approach, in which global taxonomy principles are used as a foundation, but the classification scheme is tailored to reflect the specific features of the residential building stock in North Macedonia. This ensures both compatibility with international methodologies and relevance for local seismic risk assessment.

3- METHODOLOGY

3-1- DATA COLLECTION AND PROCESSING

The assessment of residential building exposure in the Republic of North Macedonia is based on official data obtained from the State Statistical Office, including the 2021 Population and Housing Census. The dataset covers all 80 municipalities and provides aggregated information on population, dwellings, and building characteristics.

The key variables used in this study include: (i) total population, (ii) year of construction, (iii) number of floors, and (iv) structural material of buildings. The construction period is categorized into the following intervals: before 1919; 1919–1945; 1946–1960; 1961–1970; 1971–1980; 1981–1990; 1991–2000; 2001–2010; 2011–2015; 2016 and later; and unknown. The number of floors is classified as: ground floor only, G+1, G+2–3, G+4, G+5–9, G+10–19, G+20 or more, and unknown. Structural materials include reinforced concrete, concrete blocks, steel, brick masonry, stone, prefabricated wood panels, adobe, and unknown. The total built-up area per municipality and the total population living in municipalities are shown on Figure 1 and Figure 2 respectively. The spatial distribution of total built-up area indicates a strong concentration in major urban centers, particularly in Skopje. This reflects the uneven development pattern and highlights regions with higher exposure to potential seismic losses. The population distribution closely follows the pattern of built-up area, with the highest concentrations in urban municipalities. This correlation suggests that areas with dense construction also represent the highest potential human exposure in seismic events.

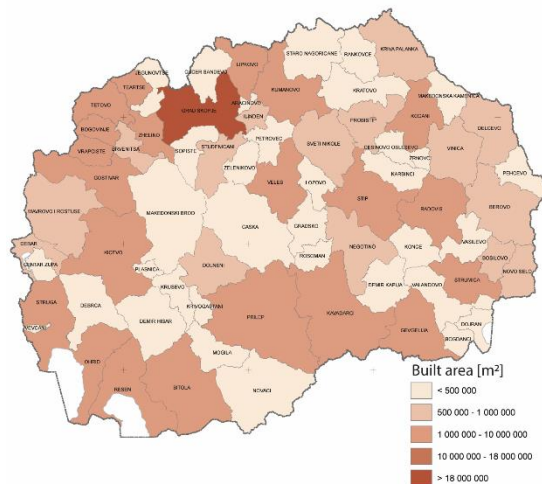


Figure 1 -Total built-up area per municipality

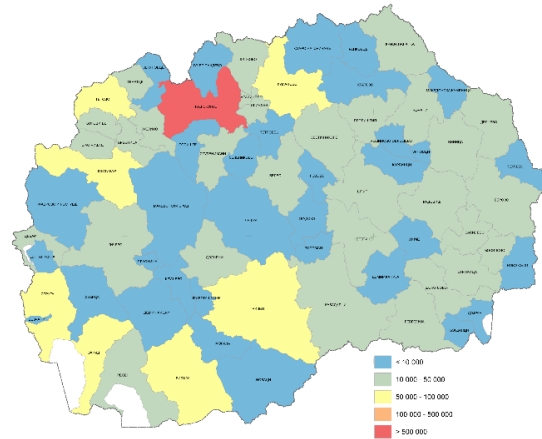


Figure 2 -Total population living in municipalities

3-2- BUILDING CLASSIFICATION FRAMEWORK

The classification of the residential building stock was developed by adapting existing global building taxonomies to locally available data and construction characteristics in North Macedonia. Buildings were classified using three primary attributes: structural material, construction period, and number of floors. These parameters were selected due to their strong influence on seismic performance and their availability in national statistical datasets.

Structural materials were grouped into broader categories reflecting typical structural systems, such as reinforced concrete (RC), masonry (brick, stone, and concrete blocks), steel, and traditional materials (adobe

and wood). The number of floors was used as a proxy for building height, which is a critical parameter in seismic response. Construction periods were used to approximate the level of seismic design applied at the time of construction.

3-3- SEISMIC CODE-BASED CATEGORIZATION

To better understand building design and construction practices across different periods in North Macedonia, it is necessary to briefly outline the evolution of seismic regulations, as documented in previous studies [8], [11], [12], [13].

Prior to 1948, no seismic regulations were in place, and buildings were constructed primarily using traditional materials such as masonry and timber, without any consideration of seismic resistance or detailing. The introduction of the first seismic provisions in 1948 marked the beginning of regulated seismic design, although these early rules were highly simplified, prescribing horizontal seismic forces of approximately 2% of the vertical load and lacking specific detailing requirements for different structural systems.

A significant advancement occurred following the 1963 Skopje earthquake, which exposed the vulnerability of the existing building stock and led to the adoption of more comprehensive regulations in 1964. These provisions introduced basic seismic design principles and initial detailing requirements for reinforced concrete and masonry structures.

Further improvements were implemented with the seismic code introduced in 1981 (enforced from 1982), which represented a major step forward in seismic design practice. This code incorporated more stringent detailing rules for both masonry and reinforced concrete buildings and introduced concepts related to ductility and energy dissipation, reflecting a more advanced understanding of structural behavior under seismic loading. In recent years, Eurocodes have been introduced and adopted in engineering practice, providing a modern framework for seismic design. However, the seismic code from 1981 remains in force and is used in parallel with the Eurocodes.

As a result, the current building stock in North Macedonia reflects structures designed according to different generations of seismic regulations, with varying levels of expected seismic performance. To account for differences in seismic design practices over time, buildings were further classified according to the seismic design codes in effect during their construction period. Three main categories were defined:

- **Pre-code buildings (before 1970):** Structures constructed without explicit seismic design provisions or with minimal consideration of seismic loads [14], [15].
- **Buildings designed under older seismic codes (1971–1980):** Structures designed according to early seismic regulations, characterized by limited ductility and lower design forces compared to modern standards.
- **Buildings designed under current seismic codes (1981 and later):** Structures designed according to more advanced seismic provisions, incorporating improved understanding of earthquake effects and structural behavior [16].

The classification into these categories was based on the correspondence between construction year intervals and the historical development of seismic regulations in the country. This approach allows for an indirect estimation of structural vulnerability based on the expected design level.

3-4- PROPOSED TAXONOMIES

In this study, the available national building data were systematically mapped onto a simplified taxonomy framework and subsequently correlated with the building classifications adopted by the Global Earthquake Model (GEM) Foundation and the HAZUS methodology. The objective was to retain the key parameters required for seismic exposure and vulnerability assessment while enabling comparison with internationally recognized taxonomy systems. The proposed taxonomy (Table 1) is based on three principal parameters: structural material, building height, and construction period.

To facilitate comparison with existing international frameworks, each category of the proposed taxonomy was linked to the corresponding GEM taxonomy attributes and HAZUS building classes. This correlation was established based on similarities in structural material, structural system, building height, and expected seismic behaviour. Categories such as reinforced concrete, masonry, steel, wood, and adobe were therefore associated with the most representative GEM material classes and HAZUS structural classes.

Since the national census data do not contain information on detailed structural systems, the correlation was performed primarily at the material, height, and code-level classification levels. A direct assignment to specific HAZUS structural subclasses (e.g., C1, C2, or C3 for reinforced concrete buildings) was therefore not

possible. Consequently, the listed HAZUS subclasses should be interpreted as representative examples that may correspond to the identified material groups rather than as exact structural classifications.

Building height was characterized using the number of storeys. For practical application, buildings were grouped into low-rise (1–3 storeys), mid-rise (4–8 storeys), and high-rise (9 or more storeys) categories. Although these groups were defined specifically for the present study, they can be directly related to the storey-based classifications used in GEM and the low-, mid-, and high-rise classes adopted in HAZUS. This correspondence enables comparison of the proposed taxonomy with existing exposure and vulnerability models without modifying the original classification systems.

The construction period is used as an indicator for the level of seismic design. Buildings are grouped into pre-code, low-code, and moderate/high-code categories, reflecting the evolution of seismic design regulations. This approximation allows the incorporation of seismic design quality into the taxonomy despite limitations in detailed historical code data.

Table 1- Proposed taxonomies

Parameter	Proposed Category	GEM Attribute	HAZUS Classification	Description
Structural Material	Reinforced Concrete (RC)	MAT: RC	C1 (Concrete Moment Frame), C2 (Shear Wall), C3 (Infilled Frame)	RC frame or wall systems
	Masonry	MAT: MUR	URM (Unreinforced Masonry)	Load-bearing masonry (brick, stone, block)
	Steel	MAT: S	S1 (Moment Frame), S2 (Braced Frame), S3 (Light Frame)	Steel frame structures
	Wood	MAT: W	W1 (Light Wood Frame), W2 (Commercial Wood)	Timber / prefabricated wood
	Adobe	MAT: ADO	URM	Sun-dried, unfired mud (clay) masonry
Height (No. of storeys)	Low-rise	H:1–3	L (1–3 storeys)	Ground to 3 storeys
	Mid-rise	H:4–8	M (4–8 storeys)	4 to 8 storeys
	High-rise	H:9+	H (9+ storeys)	9 or more storeys
Construction Period / Code Level	Pre-code	Y < 1970 / CDN	Pre-Code	No seismic design provisions
	Low-code	Y ≈ 1971–1980 / CDL	Low-Code	Limited seismic provisions
	Moderate / High-code	Y > 1981 / CDM/CDH	Moderate-Code / High-Code	Modern seismic design

The available data were first organized in a spreadsheet and classified according to the proposed taxonomy framework. Each record was assigned to the corresponding material, height, and code-level category based on the available information on structural material, number of storeys, and construction period. The total built-up area and population were then aggregated within each taxonomy class, allowing the distribution of exposure indicators across the defined taxonomy classes to be obtained at the municipal and national levels. Categories with unknown information were excluded from the comparative graphical presentation due to their relatively small share in the overall dataset. Figures 3 and 4 present the distribution of the total population and total built-up area, respectively, across different structural materials and seismic design code periods.

The results clearly indicate that reinforced concrete (RC) buildings dominate both in terms of population occupancy and total built-up area. A significant proportion of the population resides in RC structures constructed according to modern seismic codes (post-1981). This reflects the intensive urban development and reconstruction period following the introduction of more stringent seismic regulations.

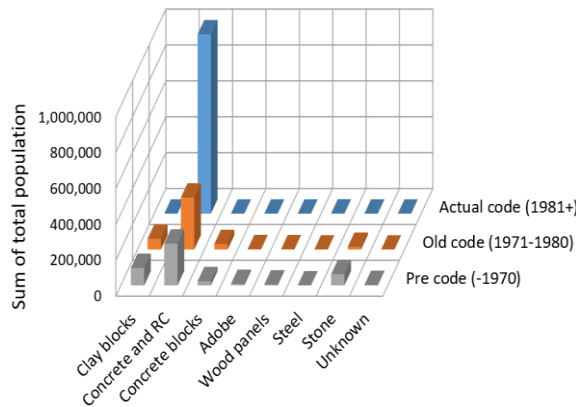


Figure 3 -Total population living in buildings from different structural materials and applied codes

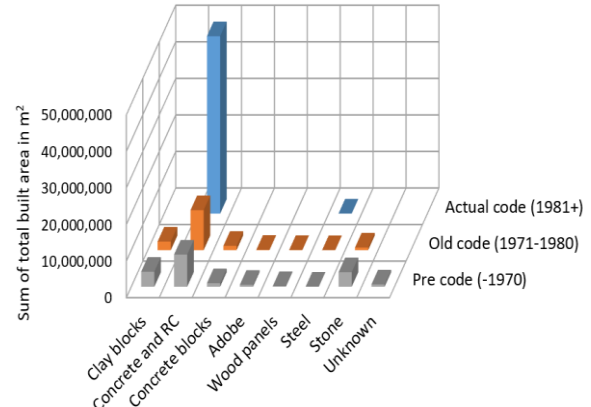


Figure 4 -Total built-up area by structural materials and applied codes

Buildings constructed under older seismic codes (1971–1980) also represent a considerable share of both population and built-up area, particularly within RC and concrete block structures. In contrast, pre-code buildings (before 1970) account for a smaller portion of the total built-up area but remain relevant in terms of seismic vulnerability, especially for materials such as masonry (brick, stone) and adobe.

Non-engineered and traditional construction types, including adobe, stone, and wood, contribute only marginally to the overall exposure in terms of area and population. However, despite their lower representation, these structures are typically associated with higher seismic vulnerability, which is critical for risk assessment. Concrete block buildings show a moderate presence across all code periods, indicating their widespread use over time, though with varying levels of seismic design consideration. A comparison between Figures 3 and 4 reveals a consistent trend, that materials with larger built-up areas (primarily RC) also accommodate the largest share of the population.

Figure 5 shows that a large proportion of the population (55%) is housed in buildings designed under current seismic codes, suggesting an overall improvement in seismic resilience at the national level. However, the presence of populations in pre-code (8%) and low-code buildings (37%) remains a critical concern for seismic risk assessment.

Figure 6 clearly shows that the building stock is predominantly composed of reinforced concrete (82%) and masonry structures (16%), with other materials contributing only marginally. Despite their relatively small share, traditional materials may significantly influence overall vulnerability due to their lower seismic resistance.

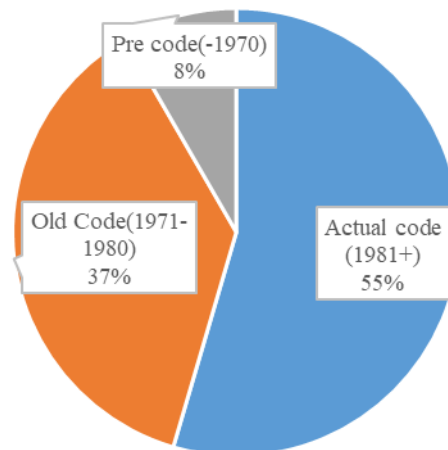


Figure 5 - Population living in buildings according to applied codes

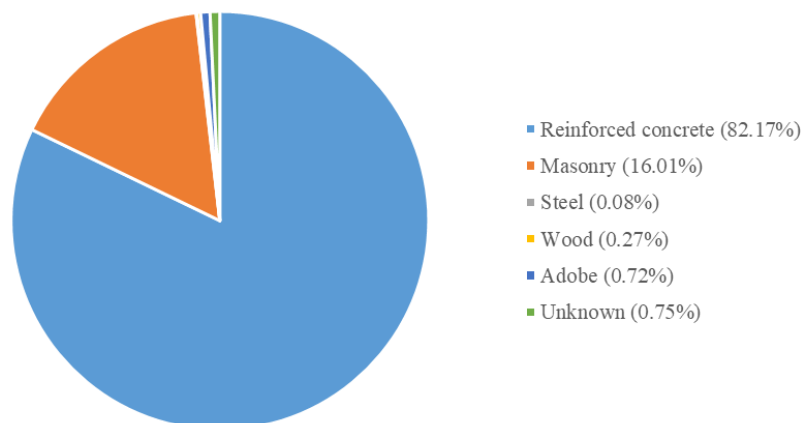


Figure 6 – Distribution of buildings according to material

The distribution of built-up area across height classes, shown on Figure 7, shows a predominance of low- and mid-rise buildings, with high-rise structures concentrated in more recent construction periods. This pattern reflects both urbanization trends and evolving construction practices.

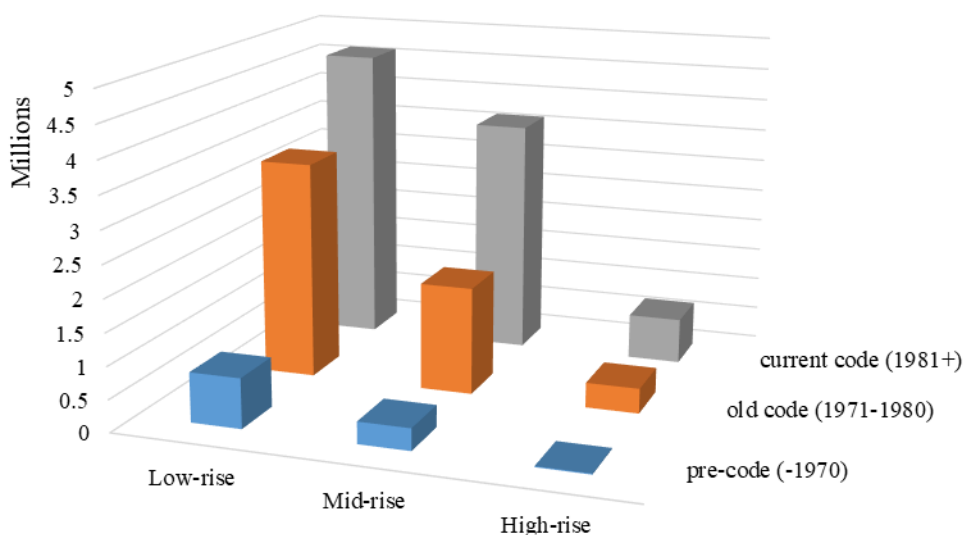


Figure 7 – Total built-up area according to height classification and codes

4- CONCLUSION

The results of the exposure analysis reveal a building stock in North Macedonia that is strongly dominated by reinforced concrete (RC) structures, particularly those constructed after the introduction of modern seismic codes. This reflects the significant influence of post-earthquake reconstruction policies and urbanization processes, especially following the 1963 Skopje earthquake, which marked a turning point in construction practices and seismic design regulations in the country.

The predominance of RC buildings designed under current codes suggests an overall improvement in the seismic resilience of the residential building stock. Modern code provisions incorporate enhanced requirements for ductility, load transfer mechanisms, and structural detailing, which contribute to better performance during seismic events. Consequently, a large portion of the exposed population is likely to be housed in structures with comparatively lower vulnerability.

However, the results also highlight the continued presence of buildings constructed before or under earlier seismic codes. Although these structures represent a smaller share of the total built-up area, they are particularly significant from a risk perspective. Pre-code and old-code buildings, especially those constructed

from masonry materials such as brick, stone, and adobe, are typically characterized by limited lateral resistance and brittle failure mechanisms. As a result, they may contribute disproportionately to potential damage and losses during earthquakes.

The analysis further indicates that traditional construction types, while limited in overall exposure, should not be neglected in risk assessments. Their higher vulnerability levels mean that even a relatively small number of such buildings can have important local impacts, particularly in rural areas where these construction practices are more common. A key finding of this study is the strong spatial concentration of both population and built-up area in the capital city. Earthquake scenarios affecting this region are expected to produce significantly higher impacts compared to other municipalities, not only due to the higher density of buildings and population but also due to the accumulation of economic assets and critical infrastructure.

The proposed methodology offers a consistent framework for national-scale seismic exposure assessment. It provides a foundation for future studies that could incorporate more detailed building-level data, refine the classification scheme, and integrate vulnerability functions for quantitative risk analysis. A limitation of the present study is that the available census data do not contain information on detailed structural systems. Future studies should integrate census data with cadastral databases, engineering documentation, and field surveys to enable a more detailed classification of structural systems and a direct mapping to specific GEM and HAZUS structural subclasses.

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