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The Role of Vulnerability Assessment in Urban Planning for Mitigating Seismic Risk

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Abstract
Natural disasters are becoming increasingly frequent, particularly in the context of rapid urbanization. As urban areas continue to expand, often in unplanned and uncontrolled ways, both infrastructure and populations are increasingly exposed to natural hazards. This uncontrolled growth frequently lacks the necessary resilience to withstand shocks, further complicating disaster preparedness and response efforts. Seismic events dominate the list of most catastrophic disasters, with six of the deadliest events in the past two decades attributed to these disasters. Disaster risk emerges from the intersection of hazard frequency, intensity, and impact with the number of exposed people and assets, as well as their vulnerability to damage. Despite vulnerability being a fundamental component of risk assessment, research often prioritizes 'hazard' and 'exposure' over an in-depth examination of 'vulnerability.' This tendency is largely due to the challenges of identifying vulnerability. This study aims to highlight the role of vulnerability assessment in urban planning for seismic risk mitigation. It begins with a theoretical review of the concept of risk assessment and its main components. Additionally, a literature review on seismic vulnerability assessment was conducted to identify the key factors that contribute to increased seismic vulnerability. The results indicate that vulnerability assessment is a critical element of risk assessment. In assessing vulnerability, a multidimensional approach is essential. Vulnerability encompasses various physical, social, economic, and built environment factors that influence urban area vulnerability to natural hazards. The complexity of vulnerability arises from the interplay of multiple variables, which vary significantly across different communities. Understanding and identifying the factors that cause seismic vulnerability, and their interactions can help direct efforts towards addressing these aspects, thus increasing the resilience of cities and urban areas.

Keywords
Vulnerability, Seismic hazard, Risk assessment, Natural disasters, Exposure

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1. Introduction
The proportion of people living in cities has been increasing in recent years due to urbanization's relentless acceleration. Recently, the rate of urban growth is at its highest point in history around the world (Labaka et al., 2019). The urban area is still expanding. As a result of this rapid urbanization which, on occasion, is unplanned, cities are facing a range of abrupt shocks brought and chronic stressors. Natural hazards are one of the greatest threats facing humanity. (UNDRR(a), 2015). Natural hazards are devastating events that often cause many casualties, huge economic losses and great destruction. One of the greatest challenges of human society over the years has always been adapting and living in the constant presence of natural hazards.

Between 2000 and 2019, the Emergency Event Database EM-DAT reported 7,348 disaster incidents, globally (EM-DAT, 2023). Approximately 1.23 million people died as a result of natural disasters worldwide, which is about 60,000 every year on average, and over 4 billion people were affected. Additionally, disasters caused global economic losses of about US$ 2.97 trillion. In 2022, as a result of 387 natural hazards worldwide was recorded by the EM-DAT, it affected 185 million people and caused the loss of 30,704 lives (Centre for Research on the Epidemiology of Disasters (CRED), 2023), and

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total losses were around US$ 270 billion (Munich Re, 2023). As shown in Figure 1, through the statistics of the last two decades of the twentieth century compared to the first two decades of the twenty-first century, you can clearly notice the huge increase in the number of natural disasters and the related increase in the volume of material and human losses. This indicates that the frequency of natural disasters is increasing.

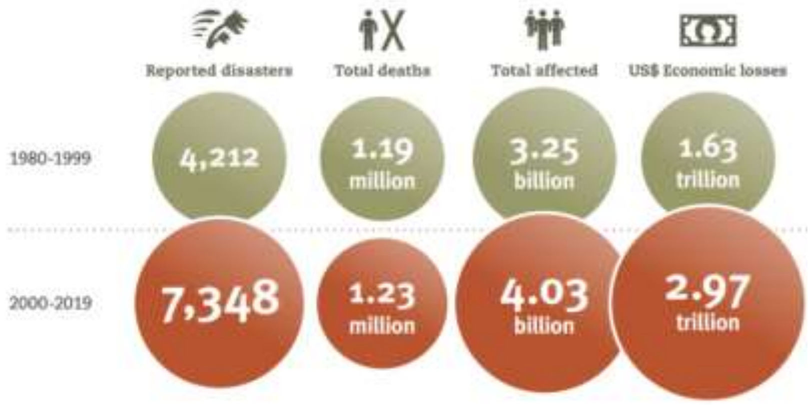

Figure 1: The volume of material and human losses at 1980-1999, and 2000-2019.
Source: EM-DAT (EM-DAT, 2023)

Over the past two decades, geophysical disasters, particularly earthquakes and tsunamis, have emerged as the deadliest natural hazards. Despite constituting only 8% of all recorded disasters, they have been responsible for 59% of disaster-related fatalities, as highlighted by the EM-DAT report. Seismic dominates the list of the most catastrophic events, with six of the ten deadliest disasters attributed to them. Notable examples include the 2004 Indian Ocean seismic and Tsunami, which claimed over 226,000 lives, the 2005 Pakistan earthquake that resulted in 73,300 deaths, the 2008 China earthquake with 87,500 fatalities, and the devastating 2010 Haiti earthquake, which killed over 222,000 people and left millions homeless. In addition to their staggering human cost, earthquakes inflict widespread infrastructure damage and lead to immense economic losses. For instance, the 2011 earthquake and tsunami in Japan caused unprecedented damages estimated at USD 239 billion, marking it as one of the costliest disasters ever recorded (Centre for Research on the Epidemiology of Disasters (CRED), 2023).

In fact, not all seismic hazards have the potential to cause disasters; rather, catastrophes are caused when a hazard is combined with vulnerable aspects of the built environment. It is necessary to examine not just the hazard features but also those of the built environment and all of its constituent parts in order to provide answers to these issues. A disaster can occur in two scenarios: the first is a lack of awareness about the presence of a hazard, and the second is insufficient preparedness for the hazard.

The first stage in creating a community resilience strategy and reducing disaster risk is conducting a disaster risk assessment (DFID, 2012). International organizations such as the WHO and UNDRR emphasize that disaster risk arises when the frequency, intensity, and impact of a hazard intersect with the number of people and assets exposed, as well as their vulnerability to damage, Equation 1 (SADC DRM IMS | Risk Components | SADC - DRM IMS, n.d.). Risk is composed of three components: hazard, exposure, and vulnerability (UNDRR(C), 2015), as shown in Figure 2. So, finding causative factors for disaster outcomes means examining risk factors in these areas".

Risk increases as more people and assets are exposed. Factors such as population growth, migration, and unplanned urban expansion, commonly referred to as urban sprawl, have led to an increasing concentration of people in areas prone to various hazards (UNDRR(C), 2015). Furthermore, community characteristics significantly define their "vulnerability" to hazards. This means that while cities may be exposed to hazards, there is no risk if vulnerabilities are absent (Yong et al., 2001). The study of 'vulnerability' is inherently complex (Schneiderbauer & Ehrlich, 2004). Consequently, research often prioritizes 'hazard' and 'exposure' over an in-depth examination of ‘vulnerability’. Despite being a fundamental component of risk assessment, a recent review study highlighted the scarcity of research on vulnerability assessment in Africa, particularly in the context of seismic vulnerability, as illustrated in Figure 3 (Diaz-Sarachaga & Jato-Espino, 2020). This study aims to conduct a theoretical review of the literature to identify the role of vulnerability assessment in urban planning for seismic risk mitigation.

$$Risk = Hazard \times Exposure \times Vulnerability$$

Equation 1: Risk components. Source: (SADC DRM IMS | Risk Components | SADC - DRM IMS, n.d.; UNDRR(C), 2015).

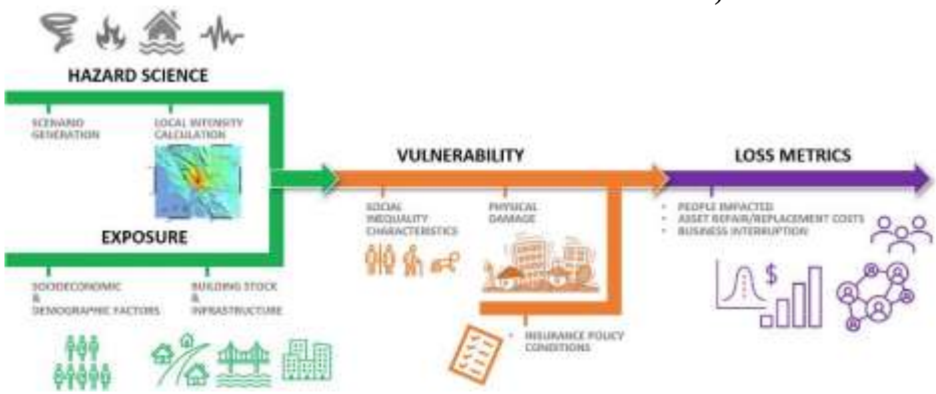

Figure 2: Risk components.
Source: Ziraoui et al. 2023 (Ziraoui et al., 2023)

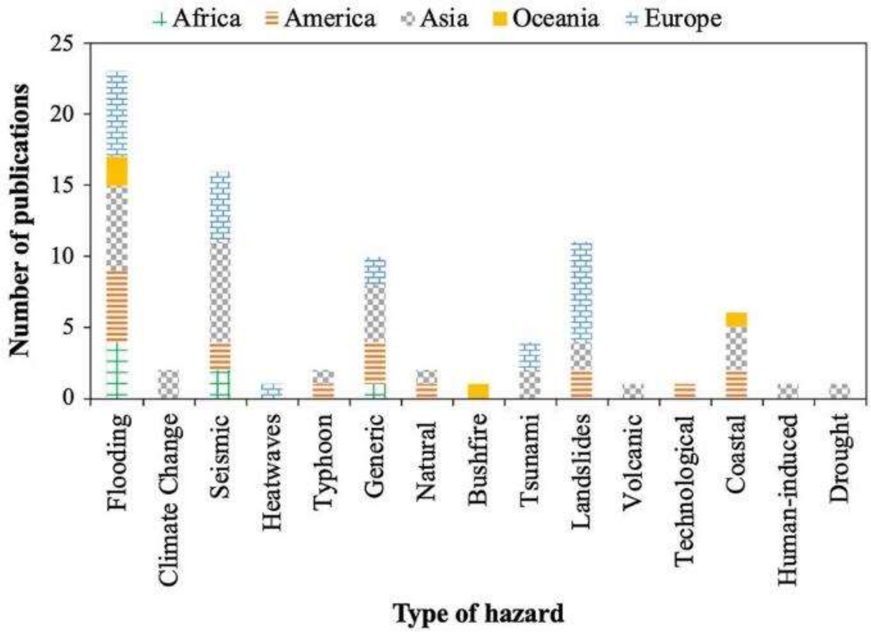

Figure 3: Seismic vulnerability assessment studies.
Source: Diaz-Sarachaga et al. 2020 (Diaz-Sarachaga & Jato-Espino, 2020).

2. Objectives and Methods

This study aims to conduct a theoretical review of the literature to identify the role of vulnerability assessment in urban planning for seismic risk mitigation. This study was conducted in three stages. In the first stage, a general review of the concept of risk assessment was carried out based on definitions and guidelines provided by international organizations such as the Federal Emergency Management Agency (FEMA), the United Nations Office for Disaster Risk Reduction (UNDRR), and the World Health Organization (WHO). In the second stage, by examining the relevant literature, the study examined the concept of the main elements of risk, which are hazard, exposure, and vulnerability. This stage of the study involved examining the relevant literature to analyze the methods and requirements for evaluating each element. In the last stage, the study conducted a deep theoretical review of the literature focusing on seismic vulnerability assessment and determined the role of seismic vulnerability assessment in mitigating seismic risks. The research also examined studies that conducted earthquake vulnerability assessments with the aim of enhancing disaster preparedness in order to extract the factors that increase seismic vulnerability. This study examines how seismic vulnerability affects mitigation and adaptation strategies, providing a deeper understanding of the mechanisms that contribute to amplifying or reducing risks in the urban environment. Overall, the study highlights the importance of proactive measures in disaster management and the role of seismic vulnerability assessments in effectively reducing the impact of seismic events.

3. Results

3.1. Hazard

Natural hazards were identified by the Federal Emergency Management Agency (FEMA) as environmental occurrences that could have an effect on society and the surrounding environment (FEMA, n.d.). It includes a wide range of diverse physical events, such as earthquakes, tsunamis, landslides, floods, volcanic eruptions, severe storms, tornadoes, and many others. Hazards exist whether or not people and land development are present, and the hazard identification is the process of recognizing and identifying potential hazards that pose a threat to a specific area. As shown in Figure 4, if we assume the presence of an area near an active volcano that is completely empty of people and property, the volcano will have no actual impact. In this case, we have two options: either to stay away from the hazard zone or to expose people and property to this risk. It is important to note that the volcano will remain active in all circumstances. However, urban development in this area leads to “exposure," where human and material elements become exposed to hazard. Additionally, the nature, design, and characteristics of these elements contribute to determining the level of "vulnerability," thereby increasing the potential impact of the hazard on the area. Here, the options for risk assessment and their integration into urban planning policies come to the forefront.

It is essential to recognize that the relationship between perils and main events is not strictly one-to-one. A single peril may be associated with multiple event categories. For example, a snow avalanche could be triggered by an earthquake, classifying it as a mass movement or geophysical event, or it might result from the weight and instability of the snowpack, categorizing it as a landslide or hydrological event. Consequently, the complexity of natural hazards and their triggering factors makes it difficult to establish a straightforward classification. The Integrated Research on Disaster Risk (IRDR) working group, established a new reference called the "Peril Classification and Hazard Glossary" (Peril Classification and Hazard Glossary, n.d.). This document is currently the primary reference for classifying natural hazards in EM-DAT (Disaster Classification System | EM-DAT Documentation, n.d.). The revised classification system consists of three hierarchical levels, ranging from the most generalized category (family) to the most specific (peril), or vice versa. In this classification, Peril is linked to the main events that caused them. The events are classified into six main categories: Geophysical, Hydrological, Meteorological, Climatological, Biological, and Extraterrestrial, as shown in Figure 5.

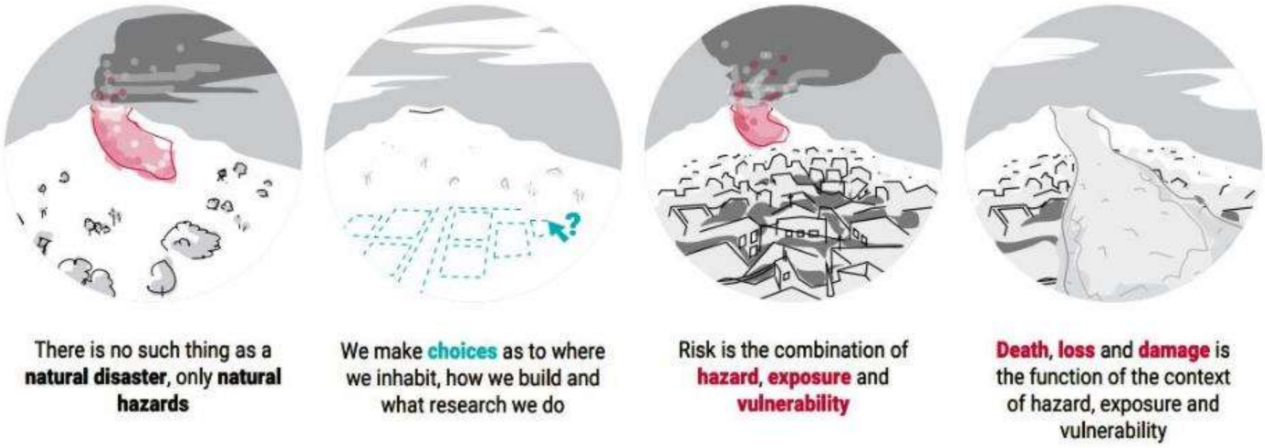

Figure 4: Illustrative example.
Source: (Global Assessment Report on Disaster Risk Reduction 2019 | UNDRR, n.d.).

Figure 5: Hazard classification.
Source: Integrated research on disaster risk (IRDR) (Peril Classification and Hazard Glossary, n.d.).

3.2. Exposure

The growing risk of natural hazards is attributed to the heightened occurrence, duration, and intensity of such events, coupled with the expansion of human settlements, infrastructure, and activities in areas exposed to these hazards. Consequently, disaster risk cannot be fully described without considering spatial exposure (Freire & Aubrecht, 2012). More people are now residing in cities than ever before, driven by the relentless acceleration of urbanization. According to United Nations projections, by 2050, urban areas will house 66% of the global population, with Asia and Africa contributing roughly 90% of this growth (Nations, 2014). According to the United Nations Department of Economic and Social Affairs (UN DESA) data booklet The World's Cities in 2018, 679 of the 1,146 cities worldwide (59 % of cities) were classified as being at high risk of exposure to at least one type of natural disaster, leaving 1.4 billion people at risk (Nations, 2018). This escalating risk is further compounded by the increasing trend of urbanization and population growth in high-risk areas.

While the terms "urban expansion," "urban growth," and "urban sprawl" are often used interchangeably, Hanberry highlighted that "urban expansion" is a broader term encompassing both planned and unplanned growth of urban areas, including the physical expansion of the city as well as the associated social, economic, and environmental changes (Hanberry, 2023). Urban expansion refers to the outward growth of towns, cities, and metropolitan areas, extending their geographic footprints into surrounding rural areas and often integrating nearby villages or towns. It also includes vertical growth, which is achieved by making existing urban spaces denser and erecting taller buildings (Lee et al., 2023). This process is influenced by various factors, including population growth, economic development, rural-to-urban migration, and policy choices. Urban expansion can happen in a controlled way, where construction is planned and managed to properly accommodate growth.

Planned growth is often referred to as "urban growth," characterized by the increase in a city's physical size over time, typically measured by land area or population growth driven by natural population increase or migration (Hardoy & Satterthwaite, 2023). In contrast, unplanned growth is referred to as "urban sprawl," a dispersed and uncoordinated expansion that consumes land inefficiently and leads to significant environmental and socioeconomic consequences (Noby et al., 2023). This rapid and often unplanned urbanization has left cities increasingly vulnerable to a range of acute shocks caused by natural disasters, as well as chronic stressors (Harrison & Williams, 2016). Furthermore, occasionally urban growth happens in the direction of areas exposed to natural disasters (Hamdy et al., 2016). This highlights the critical need for integrated approaches to disaster risk management that consider the complex interactions among natural disasters, population expansion, and urban expansion.

3.2.1. Exposure Assessment: Exposure refers to the people, property, systems, or functions that could be impacted or lost due to a hazard. It typically includes everything within the area that the hazard could affect (2009 UNISDR Terminology on Disaster Risk Reduction | UNDRR, n.d.). As previously discussed, the concept and practice of disaster risk reduction relates to systematic efforts to analyze and manage the causative factors of disaster, including by reducing the exposure of people and property to risk. Therefore, Exposure assessment to natural hazards is a critical component of disaster risk reduction efforts. Exposure assessment requires examining the interaction between natural events and the elements at exposed, such as populations, infrastructure, and other assets (Ward et al., 2020). Exposure detection typically involves overlaying hazardous locations with data related to land use and land cover (LULC), population density, infrastructure distribution, or other assets vulnerable to potential hazards (Van Westen, 2013). Numerous studies have been conducted to assess exposure to various natural hazards (Hamdy et al., 2022). Rapid urbanization has emerged as a key factor amplifying the impacts of natural disasters in urban areas. The growth of urban centers, coupled with inadequate governance, has intensified the effects of natural hazards. Factors such as the geographic clustering of major cities in hazard-prone regions, and urban growth, have collectively heightened exposure (Duzgun et al., 2011). Because urban growth is a dynamic, non-stop process, obtaining continuous updates on urban development is important in the exposure assessment process. This helps produce detailed spatial representations of elements exposed to natural hazards, enhancing the accuracy and reliability of risk assessment outputs.

3.2.2. Spatial Technologies: Routine surveying methods are often inaccurate, expensive, time-consuming, and labor-intensive. In this context, urban sprawl mapping has emerged as one of the most critical and effective applications of remote sensing, given its ability to capture phenomena with high accuracy in both spatial and temporal dimensions (Nugroho & Al-Sanjary, 2018). Remote sensing is the process of detecting and monitoring the physical characteristics of a region by measuring its reflected and emitted radiation from a distance, typically using satellites or aircraft (What Is Remote Sensing and What Is It Used for? | U.S. Geological Survey, n.d.), as shown in Figure 6. Equipped with advanced cameras, these platforms capture images of vast areas on the Earth's surface, providing perspectives far beyond what is visible from ground level. Satellite imagery is widely used for various applications, including tracking temperature changes, monitoring urban sprawl, observing shifts in farmland and forests over time, and mapping rugged terrains. This technology plays a crucial role in understanding and managing environmental changes.

One of the most important applications of remote sensing is the valuable information it provides about the physical characteristics of urban areas and the monitoring of urban sprawl. It addresses the challenges of updating datasets in traditional methods used by official urban planning departments (Wang et al., 2023). The capability to continuously monitor changes in urban land use over time enables the production of precise LULC mapping products. RS data has been successfully used to identify historical land cover changes and assess urban sprawl trends in various regions worldwide (X. Li & Gong, 2016). Monitoring and capturing changes in LULC and urban sprawl help reduce disasters caused by exposure to natural hazards.

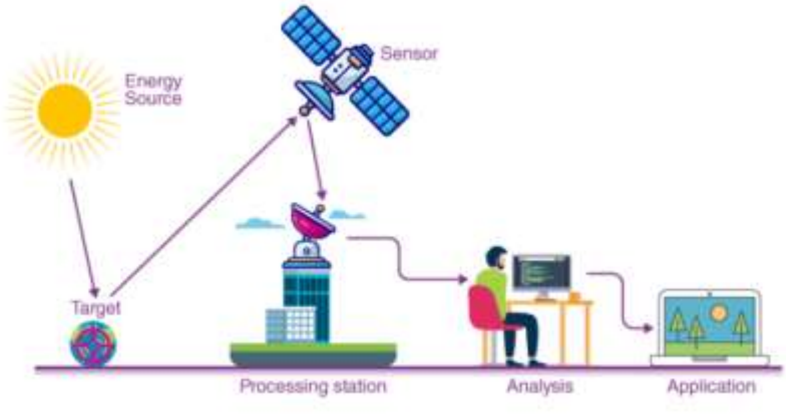

Figure 6: Remote sensing mechanism.

Source: (What Is Remote Sensing and What Is It Used for? | U.S. Geological Survey, n.d.).

RS provides Valuable data for modeling; however, this data often requires significant processing and analysis to become actionable. Among the most widely used technologies in this regard is Geographic Information System (GIS). This technology offers a robust platform for generating various options in the modeling and planning process, while also supporting the analysis of spatial data. GIS is widely employed to analyze RS data, a combination that has proven highly effective in scientific research. GIS has proven to be a powerful decision-support tool, particularly in urban planning and management. Its ability to store, process, and analyze vast datasets efficiently facilitates data-driven decision-making and decision-making processes in urban planning (Hamdy & Alsonny, 2022).

GIS not only supports the generation of LULC maps but also incorporates various spatial data analysis tools, enabling a more comprehensive examination of the data. For example, GIS analytical tools enable the extraction of key geographic factors such as slope and elevation from the Digital Information Models (DEM), which are critical for identifying areas suitable for urban development. Another example is that spatial analysis tools can analyze the distance from a particular element and examine the relationship between this distance and urban sprawl, known as driving forces, which we will discuss later in the section on predicting urban sprawl.

3.3. Vulnerability:

Vulnerability refers to the human and environmental dimensions of risk, resulting from a combination of social, cultural, economic, institutional, political, and psychological factors that influence individuals' lives and the environments in which they reside. The United Nations Office for Disaster Risk Reduction (UNDRR) defines vulnerability as "the characteristics determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, community, assets, or systems to the impacts of hazards" (UNIDSR, 2017). Another commonly cited definition of vulnerability is "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impacts of a natural or man-made disaster, acknowledging that vulnerability is shaped by numerous political-institutional, economic, and socio-cultural factors" (Garatwa & Bollin, 2002; Schneiderbauer & Ehrlich, 2004).

Several factors contribute to vulnerability, including social, physical, economic, and environmental elements. Examples include weak building structures, inadequate protective measures, lack of public education and awareness, insufficient governmental response to threats, lack of preparedness, and poor environmental resource management. The term "vulnerability" gained broader acceptance in the early 1980s to describe the extent to which people suffer from disasters, which can be determined by defining the probability of exposure to hazards and assessing the ability of affected elements to cope with these threats (Dilley & Boudreau, 2001). For example, an individual is considered vulnerable to a hazard if they are prone to physical harm, subject to damage or attack, and lack adequate defense or support to mitigate the impact of the threat (Fordham et al., 2013). In literature, the terms 'exposure' and 'vulnerability' are often used interchangeably, but they are not synonymous. While exposure is a critical risk factor, it alone does not determine vulnerability. It is possible to be exposed to a hazard without being vulnerable, or to be both exposed and vulnerable. However, in order for vulnerability to exist in the context of an extreme event, exposure is a prerequisite.

3.4. Seismic Vulnerability Assessment Methods

Many researchers have used seismic risk assessment strategies to advance towards resilient cities and communities (Hua et al., 2023). In particular, the concept of seismic vulnerability was associated with resilience to earthquake disaster in many subjects. The majority of the research focused on assessing the social vulnerability of earthquakes as well as analyzing and evaluating the vulnerability of various structures and components of the infrastructure. In the past decades, the performance of seismic assessment of buildings (S.-Q. Li, 2023) and infrastructure (Ozegbe, 2022) has attracted great attention of seismologists. Many methods have been proposed to assess the seismic vulnerability of structures, including empirical and analytical methods (Kassem et al., 2020). The analytical techniques relied on modelling the buildings' quality and their ability to withstand earthquakes. Empirical methods emerged in the form of measures based on an investigative approach to the development of post-event data, the most famous of which is the European Macro-Seismic (EMS) approach (RISK-UE), which is based on the classification of buildings into six categories of seismic vulnerability. Furthermore, (Frigerio et al) suggested an approach, called social vulnerability index, for measuring and detecting the spatial distribution of social vulnerability and for figuring out what socioeconomic factors in Italy make a specific community more vulnerable than another (Frigerio et al., 2016). In addition to numerous studies focusing on the analysis of social seismic vulnerability. Method selection is often dependent on the quality and type of available data, expert’s knowledge, available resources and the scale of the study area. The next two sections provide more detail for each method

3.4.1. Analytical Methods: These methods rely on simulation techniques to evaluate the dynamic behavior of structures under seismic loads (Silva et al., 2014). For example, specialized software is used to generate fragility curves for various structural systems. This process involves three main stages: structural analysis, which predicts the anticipated displacement of a structure under specific seismic intensity (structural response); damage assessment, which estimates the likelihood of damage based on the calculated displacements (damage measure); and loss evaluation, which determines the cost of repairs corresponding to the extent of damage (loss measure) (Hosseinpour et al., 2021). These methods, while accurate, are often constrained by substantial computational demands and the need for detailed structural and material data, which may be difficult to obtain in data-scarce environments.

3.4.2. Empirical Approaches: Empirical approaches use field observations from previous earthquakes to predict physical damage or economic losses for similar seismic settings (Hosseinpour et al., 2021). These methods rely on predefined parameters and expert judgment, enabling quick and cost-effective assessments, particularly for large-scale or preliminary studies, although their accuracy is limited by the quality of historical data and their inability to fully account for unique local conditions or specific structural characteristics (Samuel et al., 2024). Among the common methods used are the Vulnerability Index Method (VIM) and Rapid Visual Screening (RVS).

Rapid Visual Screening (RVS) is a qualitative assessment method that can be applied to a large number of buildings to classify their vulnerability. It relies on exterior observations of the buildings, without considering internal features. This method serves as an initial step in the evaluation process, providing a preliminary classification of buildings based on their construction materials and structural systems before proceeding to a more detailed assessment. The FEMA in the U.S developed a handbook for rapid visual screening of buildings for potential seismic hazards. There are 17 building types introduced for the RVS procedure and for each type, a Basic Structural Hazard (BSH) score was determined. The BSH score is about the probability of collapse for building structure. The score modifiers were based on the building properties that are affected by the seismic performance such as the number of stories, height, plan irregularity, vertical irregularity, the age of the buildings, and soil types (FEMA, 2015).

Vulnerability index methods were also based on historical data. In this approach, a field survey is conducted to develop a clear understanding of the key parameters influencing and controlling the structural vulnerability of the building. For example, the building's layout and elevation configurations, type of foundation, material type, and quality. These methodologies provide classifications of seismic vulnerability for structures. Unlike FEMA RVS, building types are not defined in this type of measurement. Instead, the determination of vulnerability categories relies on a set of indicators developed in advance based on observations and experience. Subsequently, the factors are assigned weights based on their relative importance, ranging from less significant vulnerability factors to the most critical ones. The weight values are determined through expert judgment and opinion to derive the vulnerability index (Iv), which classifies building damage under seismic excitation. Common structural vulnerability index includes the European Macro-Seismic (EMS) (Grünthal & Schwarz, n.d.).

3.5. Seismic Vulnerability Dimensions

Eastman 1999, in a review study, emphasized that vulnerability assessment requires the integration of multiple dimensions and factors, highlighting its inherent complexity (Eastman, 1999). Generally, vulnerability assessment can be categorized into four main dimensions physical, social, economic, and environmental interact to capture the vulnerability of societies to the impacts of hazards (Diaz-Sarachaga & Jato-Espino, 2020). In case of seismic vulnerability, these dimensions discuss issues such as the structures characteristic and their interaction with each other, geotechnical aspects of the study area, Infrastructure, even the demographic characteristics of the population. Vulnerability studies also consider the potential economic impact of an earthquake on a community. As well as the community's ability to respond to an emergency. In summary, exposure, sensitivity and adaptive capacity are key drivers associated with vulnerability.

Numerous studies have explored the potential of structural elements to sustain damage, which is known as physical vulnerability. These studies used indices that describe the characteristics of a building that influence its seismic vulnerability, such as shape, size, configuration, architecture, material strength, and structural integrity. Additionally, due to the interaction between earthquakes and the ground and structures, geotechnical factors were also critical. These factors include analyses of topography, soil composition, and geological formations within the region. Together, building characteristics and geotechnical factors provide a comprehensive understanding of physical vulnerability. (Columbro et al., 2022).

The built environment dimension examines urban components and their interactions. It encompasses elements such as building density, building volume, and street widths (Alizadeh et al., 2018). Additionally, studies focus on the spatial distribution of key urban features that influence the urban area's capacity versus seismic disasters. This includes proximity to facilities that enhance recovery efforts, such as medical centers, fire stations, main roads, and schools (Afsari et al., 2023a; Alizadeh et al., 2021). Furthermore, it considers proximity to potential hazards that could amplify the disaster's impact, such as fuel stations, power transmission lines, and chemical plants (Afsari et al., 2023b). Together, these factors collectively define the built environment and its vulnerability.

The social vulnerability index is used to evaluate the capacity of communities to adapt to natural disasters. It aims to identify population groups that are most likely to be affected by such events, based on social, demographic, and economic factors (Social Vulnerability Index | Place and Health - Geospatial Research, Analysis, and Services Program (GRASP) | ATSDR, n.d.). Through literature, indicators of social vulnerability can be divided into indicators of sensitivity and indicators that can increase the capacity of society. Sensitivity factors capture demographic characteristics that heighten vulnerability, including age, gender, and population density. On the other hand, Adaptive Capacity focuses on indicators that enhance a community's ability to cope with and recover from disasters, such as levels of education, income, and access to healthcare (Alam & Haque, 2022; Waly et al., 2021).

4. Conclusion

Natural disasters are increasing, especially with increasing urbanization. urban areas are constantly growing, in unplanned ways, and this growth exposes urban areas and populations to natural hazards. Additionally, this growth often lacks the resilience to withstand shocks and hinders disaster preparedness and response functions. Seismic events dominate the list of most catastrophic disasters, with six of the deadliest events in the past two decades attributed to these disasters. Rapid urban sprawl is putting pressure on cities regarding their seismic hazard resistance properties. Disaster risk emerges from the intersection of hazard frequency, intensity, and impact with the number of exposed people and assets, as well as their vulnerability to damage. Despite vulnerability being a fundamental component of risk assessment, research often prioritizes 'hazard' and 'exposure' over an in-depth examination of 'vulnerability.' This tendency is largely due to the challenges of identifying vulnerability. This study aims to highlight the role of vulnerability assessment in urban planning for seismic risk mitigation.

The results indicate that vulnerability assessment is a fundamental component of risk assessment, as it encompasses a wide range of social, cultural, economic, institutional, political, and else that interact with each other. The complexity of vulnerability arises from the dynamic interactions between these factors, which vary considerably across different communities. Understanding and identifying the factors that cause seismic vulnerability, and their interactions can help direct efforts towards addressing these aspects, thus increasing the resilience of cities and urban areas.

In assessing seismic vulnerability, a multi-dimensional approach is essential. The physical dimension focuses on the structural integrity of buildings and the influence of geotechnical factors, such as soil composition and topography, which directly impact a structure’s ability to withstand seismic events. The built environment dimension further explores urban components, including building density, street widths, and proximity to critical infrastructure, all of which affect a city's resilience to disasters. Additionally, social vulnerability plays a crucial role in determining a community's capacity to adapt and recover, with demographic and economic indicators serving as key determinants of sensitivity and adaptive capacity. A comprehensive vulnerability assessment helps identify the most at-risk communities, infrastructure, and urban elements, allowing for the implementation of targeted interventions.

This paper relied on open and freely available sources. Utilizing papers from different sources may contribute to greater diversity in results. Additionally, this study focused on seismic vulnerability assessment only. Vulnerability assessment for other hazards may involve different aspects; therefore, examining vulnerability factors and indicators across various natural hazards and dimensions would be beneficial. For future research, it may be beneficial to expand the scope of the study to include other hazards such as floods or hurricanes. By considering a wider range of hazards, researchers can gain a more comprehensive understanding of vulnerability factors and indicators. This would allow for a more holistic approach to disaster risk reduction and management.

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