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Evaluation of Different Rapid Assessment Approaches for Seismic Risk Evaluation of Masonry Structures

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Abstract

Masonry structures hold notable historical and cultural significance but exhibit inadequate seismic performance due to low-strength materials and structural limitations. This paper aims to investigate and prioritize the seismic risk of masonry buildings to support preservation strategies, enhance urban resilience, and contribute to sustainability. To achieve this, different rapid assessment methods were comparatively applied, providing a practical alternative to detailed seismic analysis, which was impractical for large building stocks. This study focused on the masonry structures of Osijek, a city characterized by moderate seismic hazard, where these buildings are vital to the cultural heritage, tourism, and identity of the local community. Risk prioritization was conducted for 105 masonry buildings using data collected through systematic field observations and measurements. Findings indicate that while rapid assessment methods provide valuable insights for identifying vulnerable structures, their sensitivity and applicability vary according to building characteristics and the available data. The comparative analysis emphasizes that some methods are more effective at detecting structural deficiencies, whereas others are more suitable for large-scale screening when resources are limited. The novelty of this study lies in identifying the efficiency and limitations of different rapid assessment approaches, thereby advancing knowledge in seismic risk prioritization and providing guidance for heritage protection and disaster risk reduction.

Keywords: Masonry Structures; Seismic Risk; Prioritization; RVS Methods; Urban Area.

1. Introduction

Following the devastating earthquakes worldwide, it has become evident that the efforts made both before and after such events are crucial. Seismic hazard analyses, geotechnical studies, earthquake analyses, and seismic performance assessments of structures carried out beforehand are essential for minimizing disaster risk, ensuring safe construction, and protecting lives and property [1-3]. Seismic hazard analyses provide the basis for engineering designs by identifying potential earthquake scenarios and ground motion levels in a given region [4, 5]. Geotechnical studies allow for accurate modelling of structure-soil interactions by determining soil properties. Based on these data, seismic analyses can predict how structures will behave under earthquake loads and identify vulnerabilities in their structural systems. Moreover, evaluating the seismic performance of structures enables the analysis of the safety of existing buildings and provides a scientific basis for decisions regarding necessary retrofitting or renovation. All these studies are an integral part of the pre-earthquake preparedness process and contribute significantly to reducing post-disaster losses, while ensuring sustainable urban development [6, 7].

Seismic performance refers to the safety of a structure, assessed based on the extent and pattern of damage it may sustain during a particular earthquake. Understanding the seismic performance of existing buildings is crucial for

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reducing potential loss of life and property in future seismic events. The widespread destruction observed in past major earthquakes highlights the importance of evaluating the earthquake resilience of existing structures and implementing appropriate preventive measures. Structural destruction and damage caused by catastrophic earthquakes worldwide highlight the necessity of investigating the earthquake safety of existing structures and implementing the required precautions. The sheer number of existing buildings makes detailed, code-compliant seismic performance evaluations for every structure impractical. Qualified personnel, economic resources, and time are often insufficient to conduct comprehensive assessments of urban and rural building stocks. Deciding which structures to examine in detail among the existing buildings requires the application of scientific methods. Different rapid assessment methods have been developed to facilitate risk prioritization among structures. Consequently, priority is given to buildings selected for detailed structural analysis. The primary goal of these methods is to identify which existing structures, within a given building inventory or defined study area, should be prioritized for examination. Following risk prioritization and detailed seismic performance evaluations, decisions regarding demolition, reconstruction, or strengthening of structures can be made more effectively and pragmatically. Diverse rapid assessment techniques have been developed for various structural typologies and are utilized to establish risk hierarchies across diverse geographical regions. In this study, a rapid assessment methodology for masonry structures was thoroughly investigated, specifically focusing on Osijek (Croatia).

Masonry structures represent a vital construction tradition that has witnessed much of human history and reflects the engineering skills and cultural heritage of past civilizations. Such structures continue to be widely preferred regionally today. A significant number of structures have been built using this construction technique. A considerable part of historical structures is made of masonry. The main principle of masonry lies in its simplicity of arranging stone, brick, or block units in a stacked structure, either with or without mortar, to form load-bearing or non-load-bearing structures [8]. Despite their simplicity and the fact that most significant historical buildings were built as unreinforced masonry, this type of structure has endured to the present day despite periods of war and, most notably, earthquakes. In many parts of the world, masonry buildings constitute the majority of both residential and monumental built heritage. A defining feature of this heritage is the notable variation in regional architectural styles, which results in a broad spectrum of structural types. Over time, construction techniques have evolved in close connection with the surrounding environment, cultural influences, and the availability of materials [9]. Masonry has recently gained renewed attention as a sustainable construction material due to its ecological properties and low environmental impact, alongside the ongoing need to maintain existing masonry structures [10].

Although rapid visual screening methods are broadly applied across various building types, this paper focuses specifically on masonry structures, which represent the dominant typology in the city of Osijek. Several studies focus specifically on the structural vulnerability of masonry buildings using rapid visual screening and related methods. One example is the Vienna study by Achs & Adam [11], which evaluates historic brick masonry buildings constructed between 1850 and 1918, adapting the Rapid Visual Screening (RVS) method to account for their structural characteristics. A survey of 375 buildings led to the development of a classification system that provides valuable insights for urban risk management and offers a framework for prioritizing buildings in need of detailed assessment or retrofitting. In Türkiye, Albayrak et al. [12] conducted a seismic risk assessment in Eskişehir, screening 1643 buildings using street surveys and an earthquake risk score system, which is based on visual inspections of structural features, including floor numbers, soft story presence, and the overall quality of construction. Each factor was assigned to a numerical penalty score, which was summed to calculate a building's final seismic risk classification. Another study applying the RVS method to masonry buildings was conducted in Chandigarh, India, by Poonam et al. [13], focusing on 120 masonry buildings in a high seismic risk zone. Research adapted pre-earthquake RVS techniques by integrating a tagging system like FEMA post-earthquake building safety assessments. Another proposed RVS method for URM structures by Aldemir et al. [14] relies on binary logistic regression analysis applied to a database of 543 buildings collected from 60 cities in Türkiye. The buildings were classified into four seismic categories according to their spectral response acceleration. In a region with high seismic risk, Arkan et al. [15] utilized the Turkish rapid assessment method on 20 traditional masonry buildings in Bitlis province, ranking them according to their level of risk.

In Annaba, Algeria, Khemis et al. [16] conducted a risk assessment on 226 unreinforced masonry buildings. Ademović et al. [17] conducted a seismic fragility evaluation of masonry buildings in two different regions of Bosnia and Herzegovina, employing a macro-seismic modelling approach. The integration of artificial intelligence (AI) and machine learning into seismic risk assessment is rapidly increasing. While effective, traditional methods often require extensive data collection, expert evaluations, and computational resources, limiting their applicability in large-scale assessments. Bektaş & Kegyes-Brassai [18] demonstrate the integration of machine learning algorithms to enhance the accuracy of Rapid Visual Screening (RVS) methods in assessing building vulnerability. Their study utilizes post-earthquake inspection data collected after the 2015 Gorkha earthquake in Nepal to train its models, achieving greater accuracy compared to traditional methods. Bektaş and Brassai's subsequent research introduced a neural network-based RVS method that incorporates building-specific parameters, and this method demonstrated superior accuracy compared to conventional approaches. RVS methods are not exclusively designed for assessing the seismic risk of individual buildings. Instead, they have been adapted and applied in broader regional hazard assessments, urban planning, and disaster mitigation strategies [16-19]. The focus of this research is on the existing masonry building inventory in Osijek the fourth-largest city in Croatia, which holds considerable economic, cultural, and historical significance. Given Osijek's location in a region with moderate seismic activity, along with the geological conditions and the considerable age of many buildings, it is crucial to assess the structural resilience of its masonry buildings. Several studies [20-23] have focused on the seismic vulnerability and risk assessment of Osijek's building stock. These works provide comprehensive overviews by classifying buildings based on structural type, key structural characteristics, and construction period. Their findings have revealed that many of the city's structures are unreinforced masonry buildings, which are particularly vulnerable to earthquakes. Collectively, these studies have enhanced the understanding of Osijek's building vulnerability profile, providing a foundation for enhancing seismic risk assessment and formulating future urban resilience strategies. However, they also emphasize the need for a more comprehensive database to improve seismic risk assessment.

This research conducted a risk prioritization for 105 masonry buildings in Osijek by applying two different rapid assessment methods commonly used worldwide. Additionally, besides the application of certain methods, other rapid evaluation methods used worldwide were also comparatively reviewed. Further information about the seismicity of the study area is provided. While Osijek has been examined in several studies focusing on seismic vulnerability and risk, each of these previous works has adopted a distinct approach, generally assessing specific urban areas using a single, standardized method. One significant reference is the study by Pavić et al. [23], which applied the macro-seismic method originally developed by Lagomarsino & Giovinazzi [24], based on the definitions set forth in the European Macro-Seismic Scale [25]. This method combines the classical theory of probability with fuzzy set theory. It employs a perceived vulnerability model to predict damage from an earthquake by correlating macro-seismic intensity with the mean damage grade. A comparable approach was also utilized by Ereš et al. [26], who applied the same method to a selected street in Osijek, as well as by Hadzima-Nyarko et al. [27], who focused on old, confined masonry structures. Additionally, Hadzima et al. [22] implemented this methodology for the assessment of an entire city block. Beyond these relatively rapid macro-seismic-based approaches, other studies have employed more detailed analytical methods. Two separate studies by Radić et al. [28, 29] addressed different aspects of seismic risk assessment in Osijek. In one study by Radić et al. [28], the capacity spectrum method was applied to estimate the probabilistic distribution of damage under seismic loading, representing an advanced level level of assessment based on structural modeling and capacity-demand comparison. Radić et al. [29], employed the Canadian rapid visual screening method to assess the seismic risk of a specific street segment.

Each of the studies applying rapid visual screening to masonry structures, both globally and specifically in Osijek, represents a case study showcasing the widespread use of RVS techniques. These studies also demonstrate adaptations of RVS methods to local building typologies and seismic conditions. In addition to these studies, the literature also includes research focused on comparing the effectiveness and applicability of different rapid assessment methods. Alam et al. [30] proposed a unified scoring system using different seismic assessment methods. Bhalkikar & Pradeep Kumar [31] analysed several rapid assessment techniques for evaluating the seismic performance of existing reinforced concrete buildings, focusing particularly on methods frequently used in India and the United States. Chieffo et al. [32] compared the fragility curves of masonry structures in Macerata, Italy. Chieffo & Formisano [33] evaluated the seismic vulnerability of buildings in the historic center of Arsita, a town impacted by the L'Aquila earthquake, using a multi-tiered approach that integrated various estimation methods and was grounded in the macro-seismic framework of the EMS-98 scale. Ceroni et al. [34] analysed and compared several simplified approaches proposed for assessing the seismic vulnerability of existing buildings. Ferreti et al. [35] proposed a simplified approach to evaluate the seismic fragility of existing masonry and reinforced concrete buildings. Separately, Nanda & Majhi [36] conducted a comparative study of rapid assessment methods; however, their analysis did not include specific building samples.

The present study addresses these limitations by adopting a broader and more comparative perspective. It applies two different RVS methodologies, the Canadian methodology and the Turkish 2013 rapid seismic risk approach, to a standardized dataset of 105 masonry buildings across Osijek. Unlike earlier studies, this study is not limited to estimating vulnerability levels or expected damage grades. Instead, it focuses on comparative risk prioritization, demonstrating how each method ranks the same buildings in terms of urgency for further assessment or intervention. Moreover, the study provides a detailed parameter-level comparison between the two approaches elucidating how factors such as seismicity, soil conditions, structural irregularities, and the interaction between structural and non-structural elements are treated differently. This enhances understanding of how international RVS approaches function in practice and facilitates future calibration or adaptation of such methods to the local conditions in Croatia and similar seismically prone urban areas.

This study begins by providing detailed information about the application of rapid assessment methods in various countries, including comparative studies of these methods. It also presents studies of similar nature conducted specifically in Osijek, the focus of the current research. After providing an overview of the seismicity of Osijek, which is the focus of the study, a comparative examination of rapid assessment methods was conducted. Following detailed descriptions of two different rapid evaluation methods applied to 105 different masonry structures, the results obtained from both methods were evaluated comparatively. The methodology employed in this study is illustrated in Figure 1.

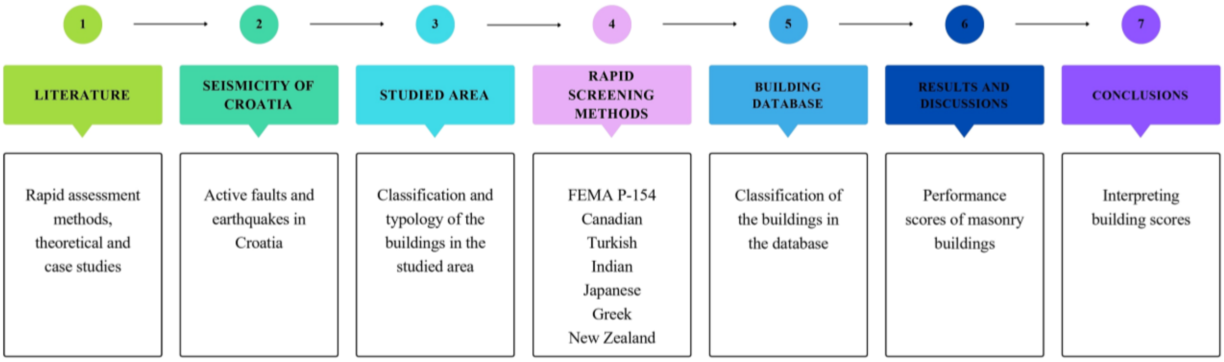
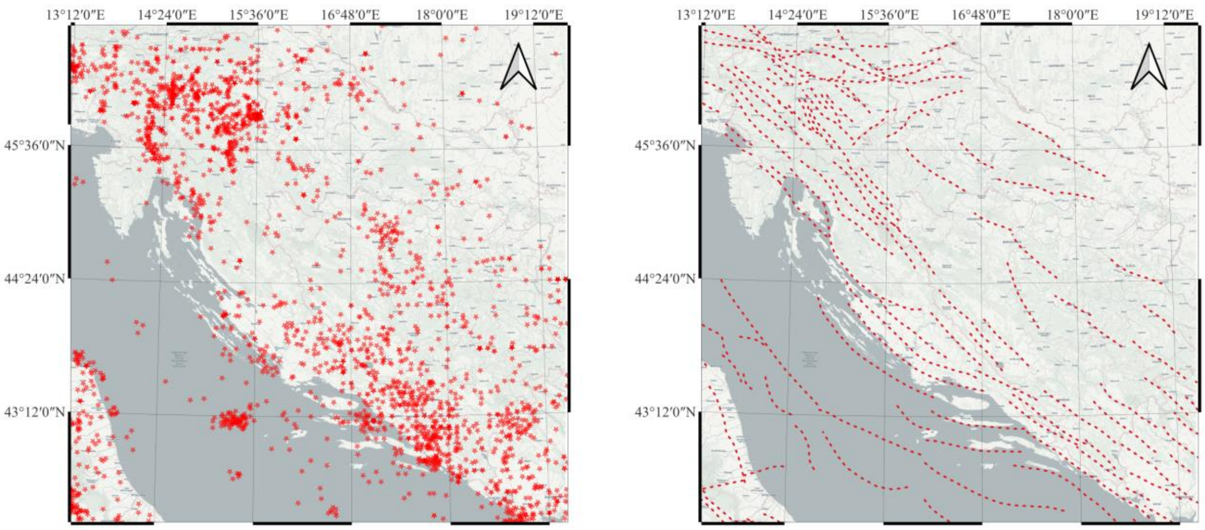


Figure 1. Methodological approach of this study

This study, which comparatively examines rapid assessment methods applied to masonry structures, is particularly significant for risk prioritization within existing building stocks in regions with notable seismic risks. Such studies are among the primary measures that can be taken regarding pre-disaster structures in modern disaster management. The study also includes different classifications, providing detailed information about the buildings in the region. While research in Osijek has primarily used macro-seismic models, providing valuable information on expected damage, a comparative evaluation of different RVS approaches has not been conducted. This study, which applies both the Canadian and Turkish rapid assessment methods to the same dataset of 105 masonry buildings, will be one of the first to comparatively examine these methods. This study will contribute to the literature by highlighting methodological differences, assessing their applicability to the Central European urban context, and discussing their relative strengths and weaknesses. This approach not only addresses the gap in comparative studies of RVS methodologies for masonry structures but also provides a knowledge base for adapting international screening methods to local conditions in Croatia and similar seismically active regions.

2. Seismicity of Croatia

The territory of Croatia, situated within the Alpine–Mediterranean seismic region, comprises several geotectonic units. The most significant among these are the Pannonian Basin in the north, the Eastern Alps, the Dinarides, the transitional zone between the Dinarides and the Adriatic Platform, and the Adriatic Platform [37]. Seismic activity is shown in Figure 2 as earthquake events (a) and as active faults (b) based on the European Seismic Hazard Model (ESHM20) [38].



a) b)

Figure 2. Seismicity of Croatia: a) earthquake events, b) active faults

Most faults in the Republic of Croatia are of the reverse type, which can be attributed to the compressional tectonic regime. Another type of fault is the strike-slip fault, where relative movement occurs in a horizontal direction. These faults form due to shear stresses acting in the crust. Located along the boundary between the African and Eurasian plates, the Mediterranean region is characterized by a complex network of fractures, faults, and tectonic structures. The primary driver of this tectonic activity is the rotation of the African plate relative to the Eurasian plate around the Euler pole, located in the eastern Atlantic. This movement results in a convergent plate boundary, leading to significant seismic activity in the region [39]. The NUVEL-1A global kinematic model [40] indicates that the African and Eurasian plates converge at rates varying from 10 mm/year in the eastern Mediterranean to 4 mm/year in the western Mediterranean, with a relative velocity between 8 and 9 mm/year. Situated within this complex collision region, the Adriatic microplate occupies the area between the Alps, the Dinarides, and the Pannonian Basin. The subduction of the microplate beneath the Dinarides largely explains the area's seismic activity. In Croatia, earthquakes result from the buildup of tectonic stresses associated with the Adriatic microplate's subduction beneath the European lithosphere along the African–Eurasian plate boundary.

Additionally, seismic activity can also arise from deformations within larger tectonic units. Historical seismicity indicates that Croatia's coastal region has been the most seismically active part of the country. Before 1900, the wider Dubrovnik area experienced the highest seismic activity. Among the eight historical earthquakes with an intensity of IX or X° MCS documented between the 15th and 17th centuries, the most significant was the catastrophic Dubrovnik earthquake of 1667 (I = X° MCS). Besides the 1667 event, several other major earthquakes along the Croatian coast, estimated at IX° MCS, underscore the region's high seismic activity [37]. Nevertheless, despite the predominance of seismic activity along the coast, the eastern parts of Croatia also have seismic potential. Due to the typical intraplate seismicity of the Pannonian Basin, where major earthquakes are uncommon, strong seismic events in this region are rare. However, historical records suggest that the possibility of significant earthquakes in this area should not be underestimated. One example is the Slavonski Brod earthquake on April 13, 1964, with a magnitude of M = 5.7 [41]. This event resulted in two fatalities and caused extensive material damage, underscoring the need to consider the seismic hazard in these areas [42]. According to the State Administration for Protection and Rescue of the Republic of Croatia, approximately 37% of the nation's territory is classified as high seismic risk, with projected earthquake intensities between VIII and IX° MCS, affecting nearly two-thirds of the population. Areas with expected intensities of VII° MCS occupy over 55% of the country and are home to slightly more than one-third of its residents.

3. Study Area

Osijek was chosen as a study area not only because of its location in a moderate seismic hazard zone, but due to several additional factors that increase its importance for seismic risk research. First, the city contains a notably number of unreinforced masonry buildings, most of which date back to a period prior to the introduction of modern seismic design standards, making them representative of vulnerable typologies in Central and Southeastern Europe. The availability of reliable building data, including construction periods, typologies, and field survey results, enabled the systematic application of both Canadian and Turkish RVS methodologies to a consistent dataset of 105 buildings. In light of these factors, Osijek represents both a fitting and strategically significant study area, providing knowledge that can inform assessments in other cities with analogous building inventories and earthquake risk levels. Figure 3 presents the geographical position of the city of Osijek.

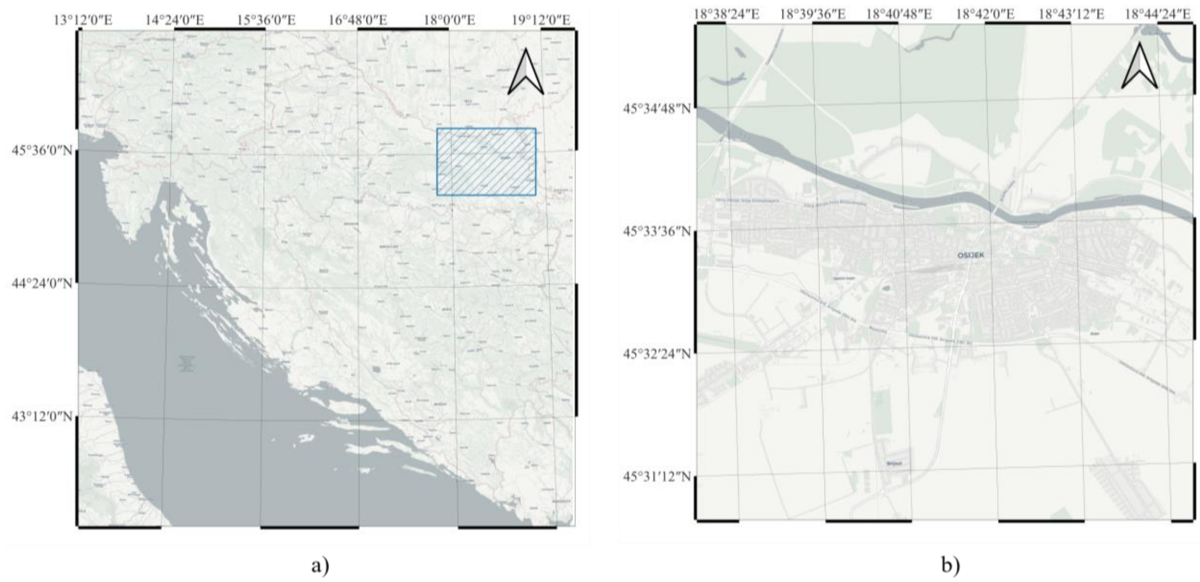


Figure 3. Geographical position of the city of Osijek: a) broader view of the region with Osijek's location marked, b) detailed view of the city of Osijek

Urban historic masonry buildings are typically not designed to resist seismic forces; their construction is primarily focused on supporting gravity loads. These structures lack the capacity to withstand the bending and shear stresses induced by earthquakes. Furthermore, poor maintenance and material deterioration also exacerbate their vulnerability. Consequently, significant damage and loss of life have occurred during recent earthquakes in historic settlements [43]. While the characteristics of regional building structures evolve, certain fundamental aspects remain consistent within each period due to the use of similar materials and structural systems. Although there is not a comprehensive database of buildings in Croatia that includes all crucial characteristics, the year of construction, as presented in Table 1, according to the Croatian Bureau of Statistics, can still serve as a good starting point for analyzing structural types.

Table 1. The percentage of the total building stock that was constructed during a specific time period

Constructed in the period	Percentage (%)
Before 1919	4.11
1919 - 1945	4.31
1946 - 1960	6.70
1961 - 1970	16.01
1971 - 1980	19.19
1981 - 1990	16.58
1991 - 2000	10.57
2001 - 2010	13.19
2011 - 2015	3.62
2016 and later	3.60
Unknown	2.12

In the aftermath of the 1963 Skopje earthquake, masonry buildings in Croatia and the former Yugoslavia were systematically constructed as confined masonry structures, incorporating horizontal tie beams and vertical tie columns. This event also prompted the alignment of reinforced concrete structural systems, including RC frames and shear walls, with new seismic design codes implemented in 1964 and 1981 [21]. A considerable number of buildings were constructed prior to the implementation of modern building regulations were put into place (Table 2). The Eurocodes for structural design were gradually introduced between 1992 and 1998. Initially, they were assigned pre-standard status under the ENV label due to challenges in harmonizing them with national legislation. The final version, published in 1998, officially adopted the European standard designation (EN) and provided guidance for implementation. In Croatia, Eurocodes began to be applied in 2005 with the release of the Technical Regulations for Concrete Structures [44], followed by updates in 2006 and 2007. By 2009, these regulations were completely replaced by a new version [45], which underwent further revision in 2010. Although buildings constructed over the last decade that comply with Eurocode 8 for seismic design represent only a small portion—approximately 4%—of the overall building stock, numerous older low- and medium-rise structures were built using stone or masonry blocks without adherence to earthquake-resistant standards. This underscores the importance of evaluating these buildings to assess their vulnerability [46].

Table 2. The development of building systems and seismic standards in Croatia [46]

Construction year	Seismic design standard	Typical structural system
Before 1948	-	Structures constructed from stone and brick masonry, which feature wooden floor systems
1948 - 1964	-	Structures with brick masonry walls and reinforced concrete floors
1964 - 1981	The first regulation for seismic design, which was implemented in 1963	The buildings are constructed using a combination of masonry with RC floors, confined masonry, and RC frames
1981 - 2008	Regulation 1981	Reinforced concrete buildings, confined masonry buildings
2005 - 2012	Pre-standards	
2010 - today	Eurocode 8	

The construction periods and classifications presented in the previous table should be interpreted as general guidelines rather than strictly defined boundaries. In practice overlaps and transitional features often occur between periods. Figure 4 illustrates examples of typical building typologies corresponding to the major construction periods in Croatia, specifically in Osijek. These examples visually demonstrate the gradual integration of seismic design concepts into Croatian building practice.

a) b) c)

Figure 4. Examples of buildings representing typical structural typologies by construction period; a) unreinforced masonry with flexible floors (pre-1948); b) and c) unreinforced masonry with rigid floors (1948–1964)

To obtain a representative overview of the existing building stock, the assessment focused on a single urban area in the city of Osijek. This location was selected due to its structural uniformity and the concentration of unreinforced masonry buildings, which are among the most seismically vulnerable construction types. All surveyed buildings consist of unreinforced masonry (URM) structures, constructed either prior to or without adherence to earthquake-resistant design regulations. While these buildings share similar wall construction, the primary structural difference among them lies in the type of floor system—ranging from flexible wooden floors in older buildings to rigid concrete slabs in those built during later periods. Figure 5 illustrates the city of Osijek, with marked areas indicating the sections of Vukovarska and Zagrebačka Streets that were included in the assessment.

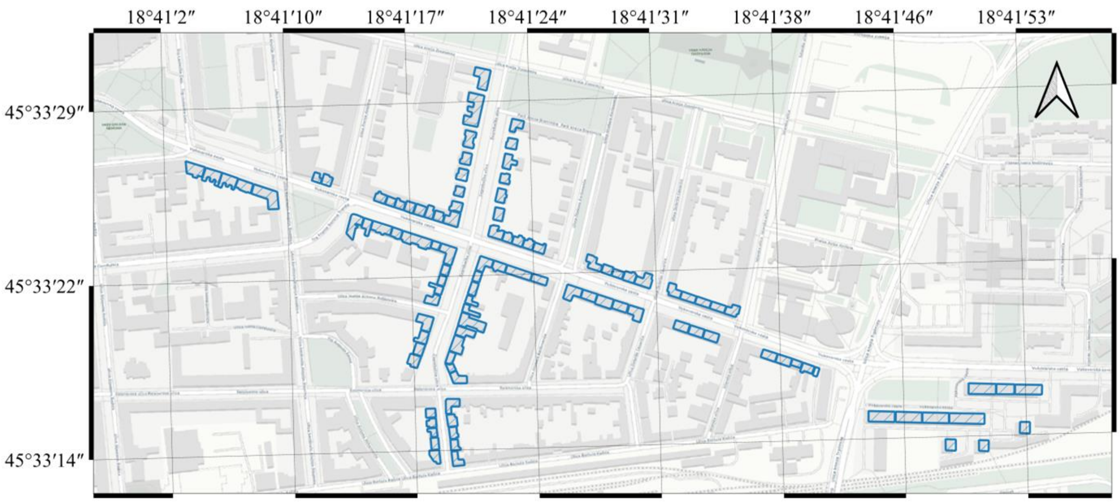


Figure 5. Overview of the city of Osijek, highlighted structures representing the building stock included in the assessment

The dataset of 105 buildings predominantly comprises residential structures, a point that is further elaborated in a subsequent chapter. The rapid visual screening method remains applicable to buildings with various functions, including non-residential structures such as schools, hospitals, and heritage monuments. However, it should be emphasized that careful consideration is required given the importance and unique characteristics of these buildings. In the present assessment, however, no such buildings were included, as the selection was confined to structures located within the designated urban area illustrated in Figure 5.

4. Rapid Visual Screening Methods

Rapid visual screening is a commonly employed technique for evaluating the seismic vulnerability of buildings, particularly in densely built urban areas where numerous structures require prompt assessment. The primary purpose of RVS is to identify buildings that may pose a hazard during an earthquake and prioritize them for more comprehensive structural evaluation. This approach relies on visual inspections and predefined criteria rather than complex structural analyses or computational modelling. However, because it depends on visual observations and expert judgment, its accuracy can vary according to the assessor's experience and the quality of the screening criteria.

4.1. FEMA P-154

One of the first RVS methodologies is FEMA, developed by the Federal Emergency Management Agency [47] in the United States. Initially introduced in 1988, this method has undergone several revisions, with the latest edition being FEMA P-154 [48]. The methodology is structured into two sequential screening levels. Completed in 15 to 30 minutes, the Level 1 assessment relies on an external visual inspection to classify the building's lateral load-resisting system into one of FEMA's predefined structural types and to identify site and configuration characteristics known to influence seismic performance. This rapid visual screening process is structured into two levels of evaluation. Level 1 is a fast, primarily exterior survey that typically takes between 15 and 30 minutes per building and does not require structural drawings or calculations. Level 2 is an optional, more detailed screening that builds on the Level 1 evaluation and is used primarily for buildings that are either critical in function or have borderline Level 1 scores. Both levels rely on a standardized data collection form and a quantitative scoring system based on structural characteristics and expected seismic performance. The central output of this method is the final Level 1 score (S_{L1}), which is calculated as:

$$S_{L1} = \max(S_{basic} + \sum M_i, S_{min}) \tag{1}$$

Each FEMA building type is associated with a predefined basic score, which varies according to the regional seismicity level. For example, unreinforced masonry buildings (URM) in very high seismicity zones are assigned a basic score of 1.1, while the same building in low seismicity zones is scored 2.4. Similarly, light wood-frame houses (W1) range from 2.1 in very high seismicity to 6.2 in low seismicity regions. These values are determined empirically based on observed collapse performance and analytical fragility functions. Table 3 presents the basic scores for selected building typologies, categorized by seismicity level.

Table 3. Basic scores assigned to selected FEMA building types as a function of regional seismicity level [48]

FEMA type	Description	Basic score				
		VH	H	MH	M	L
URM	Unreinforced masonry wall	0.9	1.0	1.2	1.7	3.2
W1	Wood light frame	2.1	3.6	4.1	5.1	6.2
RM2	Reinforced masonry wall	1.1	1.7	1.8	2.1	3.7
C1	Concrete moment-resisting frame	1.0	1.5	1.7	2.1	3.3
S1	Steel moment-resisting frame	1.5	2.1	2.3	2.7	3.8

The current edition of the methodology is structured around a quantitative scoring system that reflects the collapse probability under ground shaking corresponding to the maximum considered earthquake (MCER), which is adjusted, or local soil conditions and seismicity. The methodology defines five seismicity regions based on MCER spectral acceleration values (Ss and S_1) at the building's location, as shown in Table 4.

Table 4. Classification of a seismic region from the MCER spectral response [48]

Seismicity region	Spectral acceleration response S_s (short-period)	Spectral acceleration response S_l (long-period)
Low	$S_s < 0.250$g	$S_l < 0.100$g
Moderate	$0.250\text{g} \leq S_s < 0.500$g	$0.100\text{g} \leq S_l < 0.200$g
Moderately high	$0.500\text{g} \leq S_s < 1.000$g	$0.200\text{g} \leq S_l < 0.400$g
High	$1.000\text{g} \leq S_s < 1.500$g	$0.400\text{g} \leq S_l < 0.600$g
Very high	$S_s \geq 1.500$g	$S_l \geq 0.600$g

The summation term represents the cumulative impact of score modifiers, as presented in Table 5, which are numerical penalties or bonuses assigned based on specific structural or site-related vulnerabilities. These modifiers include vertical and plan irregularity, construction date, soil type, pounding hazard, damage or deterioration.

Table 5. Scoring matrix for Level 1 data collection form, used to assess selected building types in high-seismicity areas [48]

FEMA type	URM	W1	RM2	C1	S1
Basic score	1.0	3.6	1.7	1.5	2.1
Severe vertical irregularity	-0.7	-1.2	-0.9	-0.9	-1.0
Moderate vertical irregularity	-0.4	-0.7	-0.5	-0.5	-0.6
Plan irregularity	-0.4	-1.1	-0.7	-0.6	-0.8
Pre-Code	0.0	-1.1	-0.5	-0.4	-0.6
Post-Benchmark	NA	1.6	2.1	1.9	1.4
Soil type A or B	0.3	0.1	0.5	0.4	0.4
Soil type E (1-3 stories)	-0.2	0.2	-0.1	0.0	-0.2
Soil type E (> 3 stories)	-0.2	-0.3	-0.6	-0.5	-0.6
Minimum score, S_{min}	0.2	1.1	0.3	0.3	0.5

Individual score modifiers are determined by evaluating the likelihood of collapse associated with variations in specific building characteristics. However, simply summing multiple modifiers can overstate the combined impact of adverse conditions, potentially resulting in a final score below zero. A negative score would imply a collapse probability exceeding 100%, which is physically impossible. To prevent this, a minimum score is applied, set according to the worst-case combination of soil type, plan and vertical irregularities, and the building's age. FEMA recommends a default minimum value of 2.0. Buildings scoring below this threshold are prioritized for detailed structural assessmenttypically conducted following ASCE/SEI 41 procedures, whereas structures with higher scores may be deemed acceptable, unless they are critical facilities or house vulnerable populations.

Level 2 screening in FEMA P-154 is an optional but more refined evaluation process that builds directly upon the findings of Level 1. It is intended for buildings of higher functional importance, those with borderline final scores (e.g. S_{L1} near 2.0), or buildings displaying characteristics that are difficult to fully assess visually. While Level 1 relies on rapid field observations, Level 2 incorporates additional engineering judgment, more nuanced modifiers, and, in some cases, limited documentation review. It maintains the same fundamental scoring framework but allows for greater differentiation among buildings that may appear similar under Level 1 criteria. The Level 2 scoring procedure builds directly on the results of Level 1 but introduces additional refinement to account for more detailed structural characteristics. The first step is to take the final Level 1 score, denoted as S_{L1}, and remove the vertical and plan irregularity modifiers applied during Level 1. This gives an adjusted base score S', calculated as:

$$S' = S_{L1} - V_{L1} - P_{L1} \tag{2}$$

where V_{L1} and P_{L1} represent the vertical and plan irregularity modifiers used in Level 1 scoring. These modifiers are subtracted to avoid double-counting, since more detailed equivalents will be applied in the following step. Once the adjusted score is determined, Level 2 introduces refined irregularity modifiers and additional adjustments based on structural and non-structural features. The final Level 2 score is then computed as:

$$S_{L2} = S' + V_{L2} + P_{L2} + \sum M_i \tag{3}$$

In this Equation, V_{L2} and P_{L2} represent updated modifiers for vertical and plan irregularities, respectively, based on more specific information such as geometry, diaphragm behavior, and load path discontinuities. The term M includes additional Level 2 modifiers, which may account for retrofit conditions, redundancy, diaphragm flexibility, or significant nonstructural hazards. This multistep refinement makes Level 2 more accurate than Level 1, especially for buildings with complex layouts, partial retrofits, or limited documentation. Vertical irregularities include conditions such as sloping sites, vertical discontinuities, and elevation weaknesses. W1 buildings on steep slopes receive a −0.9 modifier, while other types receive −0.4. Features like cripple walls, garages below occupied floors, and open-front façades are penalized from −0.7 to −1.4. Setbacks are rated based on geometry (−0.7 for outboard, −0.4 for inboard), with additional deductions for in-plane offsets (−0.2), short columns or piers (−0.4), and split-level floors (−0.4). Where no specific condition applies, generic penalties of −0.7 or −0.4 may be used. Plan irregularities are evaluated separately. Torsional irregularity incurs −0.5, non-parallel systems and reentrant plans −0.2, and large diaphragm openings −0.5. General plan irregularities may also be penalized by −0.5. Additional modifiers include −0.5 for poor redundancy, +0.3 for good redundancy, and up to −0.9 for pounding hazards. Documented seismic retrofits receive +0.5, while flexible diaphragms and falling hazards carry −0.3 each.

Determining an appropriate threshold for the final score remains one of the most complex aspects of the rapid visual screening process. This decision ultimately reflects a balance between societal risk tolerance and the trade-off between mitigation costs and safety benefits and must therefore be addressed at the community or policy level. Conservatism inherent in this estimate and the actual fraction of building area that may collapse, new code-compliant buildings are expected to correspond to an average score of approximately S = 2.5. For existing buildings, a slightly lower score is considered reasonable, and S = 2.0 is commonly adopted in RVS applications to distinguish potentially inadequate buildings. Selecting a higher cutoff implies greater safety but entails higher costs, whereas a lower cutoff accepts increased seismic risk in exchange for reduced evaluation and retrofit effort.

4.2. Canadian Rapid Assessment Method

The National Research Council of Canada developed the Manual for Screening of Buildings for Seismic Investigation [49] in 1993 as a pre- and post-disaster vulnerability assessment method, primarily based on FEMA 154. The evaluation considers the region's seismic characteristics, including expected ground motion intensity and local soil conditions. The seismic priority index (*SPI*), which combines structural and non-structural indicators, is employed to categorize buildings according to their vulnerability. This classification helps prioritize structures requiring detailed seismic assessment or retrofitting measures. The methodology employs a numerical scoring system aligned with Canada's National Building Code seismic design requirements. As a screening tool, it ranks buildings according to their seismic risk, facilitating the identification of those requiring in-depth evaluation. The evaluation targets the main system responsible for resisting lateral forces in each building, while also taking into account other structural and non-structural factors affecting seismic performance. Data collection and decision making are conducted on-site, with each evaluation typically taking 15 to 30 minutes, depending on the building's size [50]. While RVS techniques provide preliminary estimations, it is crucial to validate the results through more comprehensive analyses [51].

The seismic priority index (*SPI*) is used to assess and rank buildings based on their seismic vulnerability, helping to determine which buildings require further evaluation or retrofitting. This index considers several key factors, including structural integrity, occupancy, and building importance. In this study, data were collected from 105 buildings, focusing on key factors that influence their seismic performance. SPI evaluates building seismic risks by considering multiple factors, one of the most important being seismicity, which represents the maximum expected ground motion at a given location. Foundation conditions also play a crucial role, buildings founded on soft or unstable soils are more susceptible to damage due to amplified seismic forces. Additionally, structural irregularities, such as soft stories or degraded structural elements, can considerably reduce a building's seismic capacity, making it more prone to major damage or failure. Non-structural vulnerability is another crucial factor, as the failure of non-load-bearing components—such as partition walls, ceilings, or essential equipment—can pose significant hazards. The collapse of these elements may cause injuries or disrupt critical infrastructure required for post-disaster operations. Additionally, the functional importance of a building plays a key role in seismic risk assessment. Structural failure has far more severe consequences in buildings with high occupancy or essential services, such as hospitals and emergency response facilities, than in lower-priority structures like storage or utility buildings. The seismic priority index (*SPI*) can be determined using the following Equation:

$$SPI = SI + NSI \tag{4}$$

where *SI* denotes the structural index which refers to possible damages or defects in the building's structural components, while *NSI* represents the non-structural index, referring to possible damages and defects of non-structural parts of building. The corresponding values are presented within the intervals shown in Table 6.

Table 6. Intervals of Seismic Priority Index [49]

Seismic priority index	Seismic priority
< 10	Low priority buildings
10 – 20	Medium priority buildings
21 – 30	High priority buildings
> 30	High risk buildings

The value of the structural index, *SI,* can be determined following the Equation:

$$SI = A \cdot B \cdot C \cdot D \cdot E \tag{5}$$

The seismicity factor, *A*, is derived from an analysis of seismic data presented in both current and past editions of the National Building Code of Canada, with values ranging from 1.0 to 4.0, as presented in Table 7.

Table 7. Values of seismicity factor [49]

	Design code	Effective seismic zone				
		2 (0.08g)	3 (0.11g)	4 (0.16g)	5 (0.23g)	6 (0.32g)
Seismicity factor (A)	Pre -65	1.0	1.5	2.0	3.0	4.0
	65-84	1.0	1.0	1.3	1.5	2.0
	Post -85	1.0	1.0	1.0	1.0	1.0

The soil condition factor, *B*, is determined by the following Table 8.

Table 8. Values of soil condition factor [49]

	Design code	Base soil category				
		Rock or stiff soil	Stiff soil (> 50 m)	Soft soil (> 15 m)	Very soft soil	Unknown soil
Soil factor (B)	Pre -65	1.0	1.3	1.5	2.0	1.5
	Post -65	1.0	1.0	1.0	1.5	1.5

Factor *C* reflects the seismic resistance of the structural system. A lower value of *C* (e.g., 1.0) represents a structure with good seismic performance, or one specifically designed for earthquake resistance, whereas higher values (up to 3.5 for unreinforced masonry buildings) indicate poor seismic performance. Values of factor *C* are presented in Table 9.

Table 9. Values of structural system factors [49]

	Design code	Structural system						
		Wood		Concrete		Masonry infill	Masonry	
		WLF	WPB	CMF	CSW	SIW, CIW	RML, RMC	URM
Structural system factor (C)	Pre -70	1.2	2.0	2.5	2.0	3.0	2.5	3.5
	1970	1.2	2.0	1.5	1.5	2.0	1.5	3.5
	Post -70	1.0	1.0	1.0	1.0	1.0	1.0	1.0

The irregularity factor, *D*, accounts for various structural irregularities or deficiencies that heighten seismic vulnerability, including vertical and horizontal irregularities, short columns, soft-story effects, pile-driving effects, modifications, and material deterioration. It is calculated as the product of individual irregularity factors, with a maximum allowable value of 4.0 [42]. Values of factor *D* are presented in Table 10.

Table 10. Values of irregularity factor [49]

	Design code	Irregularities					
		Vertical	Horizontal	Short columns	Soft story	Pounding	Other
Irregularity factor (D)	Pre -70	1.3	1.5	1.5	2.0	1.3	1.3
	Post -70	1.3	1.5	1.5	1.5	1.3	1.0

A building's significance factor *E* is determined by its purpose and occupancy level and is classified into five groups: low occupancy ($N < 10$), average occupancy ($10 < N < 300$), high occupancy ($301 < N < 3000$), very high occupancy ($N > 3000$), and buildings with special requirements as defined by the owner or relevant authorities. Values of factor *E* are presented in Table 11.

Table 11. Values of significance factor [49]

	Design code	Building significance				
		Low occupancy	Average occupancy	High occupancy	Very high occupancy	Special requirements
Significance factor (E)	Pre -70	0.7	1.0	1.5	2.0	3.0
	Post -70	0.7	1.0	1.2	1.5	2.0

The non-structural damage index (*NSI*) is based on three primary factors: the risk of falling elements that could endanger lives or disrupt essential services after a disaster, the building's importance, and the soil conditions. The *NSI* can be determined using the following Equation:

$$NSI = B \cdot E \cdot F \tag{6}$$

The factor *B* represents soil conditions, while E reflects the building's importance. Factor *F* is taken as the greater of F_1 and F_2, where F_1 accounts for falling hazards that pose a risk to life, and F_2 considers hazards that could impact vital operations (as detailed in Table 12). If no specific hazards are identified, these factors are assigned a default value of 1.0. However, the risk associated with non-structural elements tends to be higher in flexible or deteriorated buildings, leading to F_1 and F_2 values ranging between 3.0 and 6.0 [42]. Values of factors F_1 and F_2 are presented in Table 12.

Table 12. Values of nonstructural hazard factor [49]

Nonstructural hazard		Description	Design code	No	Yes	Yes*
F_1	Falling hazards to life	**Exterior:** masonry chimney, parapet, heavy or stone panels, insecure glazing, canopy over exits/stairwells	Pre -70	1.0	3.0	6.0
		Interior: heavy elements; masonry partitions; fragile glazing near exits; shelves that may fall near people	Pre -70	1.0	2.0	3.0
F_2	Hazard to critical operations	Equipment required for uninterrupted functionality of special-use buildings. Owners and authorities must ensure stability of critical components needed for essential function.	Any year	1.0	3.0	6.0

Yes* – applies only if one or more of the following structural irregularities are present SMF, EMF, soft story, torsion (asymmetry).

4.3. Turkish Rapid Assessment Method

The first stage evaluation method for identifying risky buildings was formalized in the regulation [52] published by the Ministry of Environment and Urbanization in Türkiye. This regulation outlines the parameters to be considered in the first stage evaluation method of buildings and specifies the methodology for calculating performance scores. This method, in this study denoted as TR-R, has been developed specifically for masonry and mixed structures.

Each building examined receives additional points based on the number of floors and its location within a designated hazard zone. Conversely, points are deducted by considering specific values assigned to each negative parameter. The parameters considered in this method for masonry and mixed structures include: type of masonry building, number of free stories, building order, current condition and visual quality, plan irregularity, vertical irregularity, hill or slope effect, negative aspects of out-of-plane behavior, roof type, earthquake hazard, and local soil condition. The building's load-bearing system is classified into one of the following types: unreinforced masonry, confined masonry, reinforced masonry, a mixed system consisting of masonry walls combined with a reinforced concrete frame. The number of stories refers to floors above the foundation, and for buildings with varying heights, the tallest section is considered. The collision effect, which is relevant for neighboring buildings, occurs when adjacent structures differ in the number of floors or when their floor levels are misaligned. The apparent quality of the structure is categorized into three levels: good, medium, and poor.

However, accurately determining this classification depends on multiple factors. First, the individual responsible for collecting information about the structure must be trained and experienced structural systems and building materials. The assessment will determine the building's plan geometry, wall-to-gap ratio, and the presence of joists or lintels. Plan geometry is categorized as either regular or irregular. Facade wall lengths in two perpendicular directions are measured at the critical floor, generally the ground floor. The effective wall length at this level is determined by the ratio of door and window openings along the front or side facades. When openings cover less than one-third of the total facade length, the wall is classified as "High". If openings occupy between one-third and two-thirds of the facade, it is classified as "Medium". When more than two-thirds of the facade is covered by openings, the wall is considered to have a "Low" effective wall amount. The vertical wall gap arrangement, differences in floor numbers across facades, and the presence of soft floors will be assessed. Vertical gap arrangements are classified into three categories: "Regular," "Less Regular," and "Irregular." If the window and door openings on the floors are perfectly aligned, the arrangement is defined as "Regular". Conversely, if the openings are staggered, it is classified as "Irregular". Buildings that fall between these two limiting conditions are classified as "Less Regular". The expression used to apply the method is provided below:

$$PP = TP + \Sigma O_i \cdot OP_i + YSP \tag{7}$$

Here, *PP* is defined as the performance score, *TP* is the base score as presented in Table 13, *OP* is the negativity score for current status and visual quality as shown in Table 14, which also includes geometry, wall amount, and lintel presence as described in Table 15. Vertical irregularity, including space layout, floor difference, and soft story, is presented in Table 16, while the position of the building relative to surrounding structures is documented in Table 17. *YSP* is defined as the structural system score, with a value of zero assigned to unreinforced masonry. By applying this method to buildings within the study area, a performance score (*PP*) is calculated for each building. These scores are then ranked in descending order, enabling the establishment of risk priorities among different regions based on the distribution of the calculated scores.

Table 13. Base scores for masonry structures [15]

Number of stories	Region I	Region II-III	Region IV
	MYI ≥ 0.4g	0.2g ≤ MYI < 0.4g	MYI < 0.2g
1	110	120	130
2	100	110	120
3	90	100	110
4	80	90	100
5	70	80	90

Table 14. Scores for the building's current condition and its visual quality deficiencies [15]

Current condition and visual quality		
Material (0/1/2)	Workmanship (0/1/2)	Damage (0/1)
-10	-5	-5

Table 15. Negativity scores in the plan of masonry structures [15]

Irregularity in plan			
Number of stories	Geometry (0/1/2)	Wall amount (0/1/2)	Lintel (0/1)
1	-5	-5	-5
2	-10	-5	-5
3	-10	-10	-5
4	-15	-10	-5
5	-20	-15	-5

Table 16. Estimated scores for vertical irregularity of masonry structures [15]

Number of stories	Vertical irregularity		
	Space layout (0/1/2)	Floor difference (0/1)	Soft story (0/1)
1-2	0	-5	0
2	-5	-5	-5
3	-5	-5	-5
4	-10	-5	-10
5	-10	-5	-10

The presence of adjacent or detached buildings significantly affects their structural response to seismic events. In this context, the negativity scores related to building order for masonry structures—reflecting their interaction with neighboring buildings—are presented in Table 17.

Table 17. Negativity scores foreseen for building order in masonry structures [15]

Building order – Floor level				
Isolated	Adjacent Middle-Same	Adjacent Corner-Same	Adjacent Middle-Different	Adjacent Corner-Different
0	0	-5	-5	-10

Examples illustrating the consideration of parameters in this method are provided in the following figures. Based on the structural system, each building was classified as unreinforced masonry and reinforced masonry, confined masonry, or mixed (masonry walls with RC frames), with examples shown in Figure 6. In this study, all examined buildings were classified as unreinforced masonry.

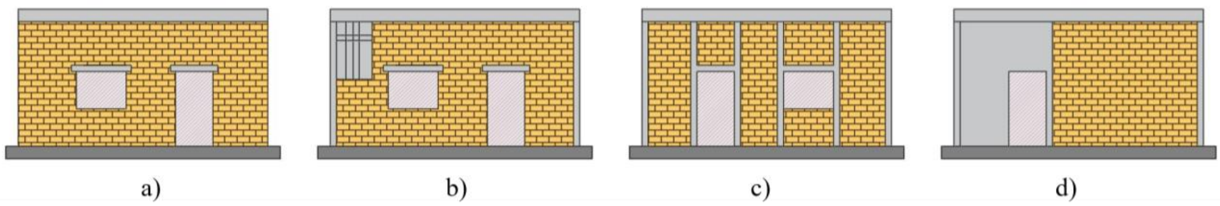


Figure 6. Structural types of masonry building: a) unreinforced masonry, b) reinforced masonry, c) confined masonry, d) reinforced concrete frames and masonry wall

The tallest facade, measured from ground level, is used to determine the number of free stories. Examples illustrating various cases are provided in Figure 7.

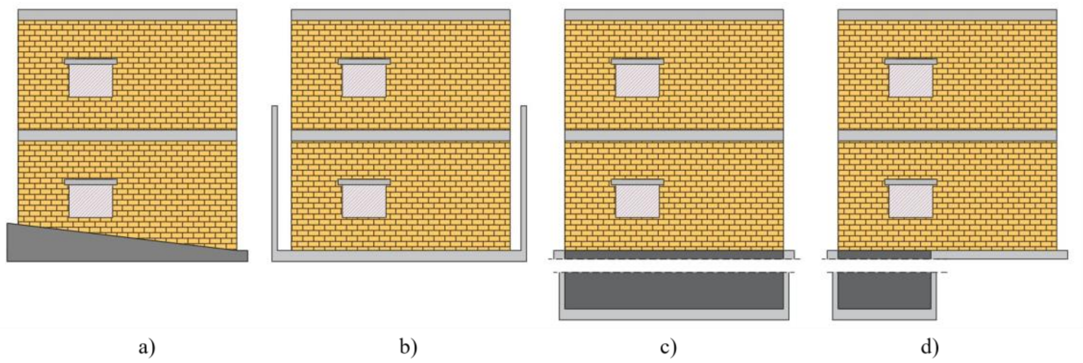


Figure 7. Examples for specifying the number of stories in 2-story buildings, considering: a) the effect of a hill slope, b) below-ground levels, c) a full basement, and d) a partial basement

Due to the risk of pounding, the location of adjacent buildings affects their earthquake performance. Edge buildings are especially vulnerable, particularly when their floor levels differ from those of surrounding structures. This parameter considers both building alignment and differences in floor level. Examples illustrating how a building's position is determined are provided in Figure 8.

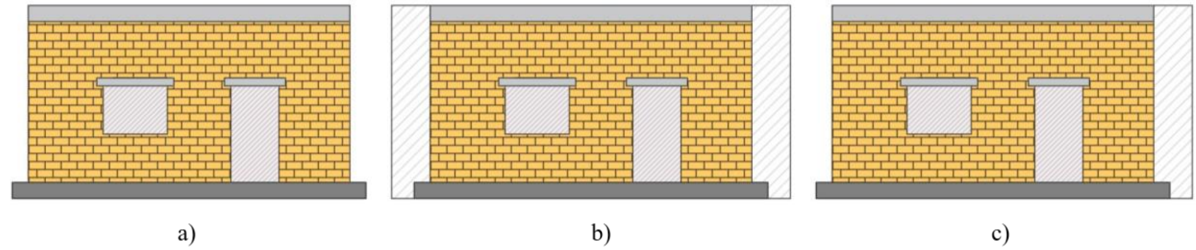


Figure 8. Building arrangement, showing: a) separate structures, b) an adjacent middle or corner, c) an adjacent edge

When evaluating an adjacent building, their floor levels must be considered as differences in floor elevations between neighboring structures can cause a collision effect during an earthquake. Examples are presented in Figure 9.

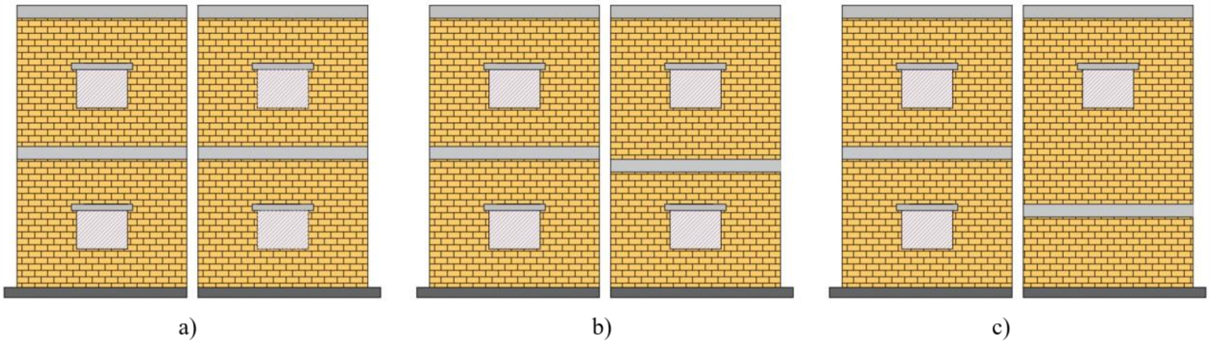


Figure 9. Floor level alignment in adjacent buildings, showing: a) the same levels, b) the same levels (limit condition), and c) different levels

Plan geometry is used to classify a building's layout as regular, irregular, or extremely irregular. Figure 10 illustrates the various conditions associated with this classification.

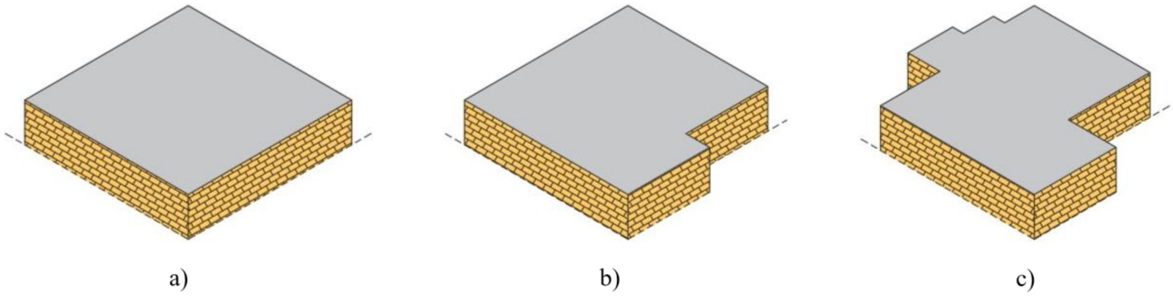


Figure 10. The classification of building plans according to their geometry, showing: a) regular, b) irregular, c) extremely irregular plan

On the critical floor, typically the ground floor, facade wall lengths are measured along two perpendicular directions, as illustrated in Figure 11. Wall coverage is classified as high if openings such as doors and windows occupy less than one-third of the facade length. Coverage is considered medium when openings account for between one-third and two-thirds of the facade, and low if openings exceed two-thirds of the total facade length.

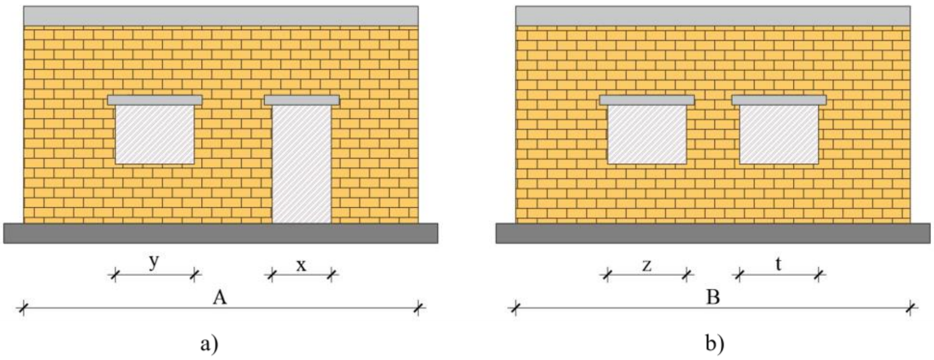


Figure 11. Measurements required to determine the insufficient amount of wall, shown for: a) the front facade, and b) the side facade

The vertical spacing of door and window openings in a building is classified as regular, less regular, or irregular, as illustrated in Figure 12.

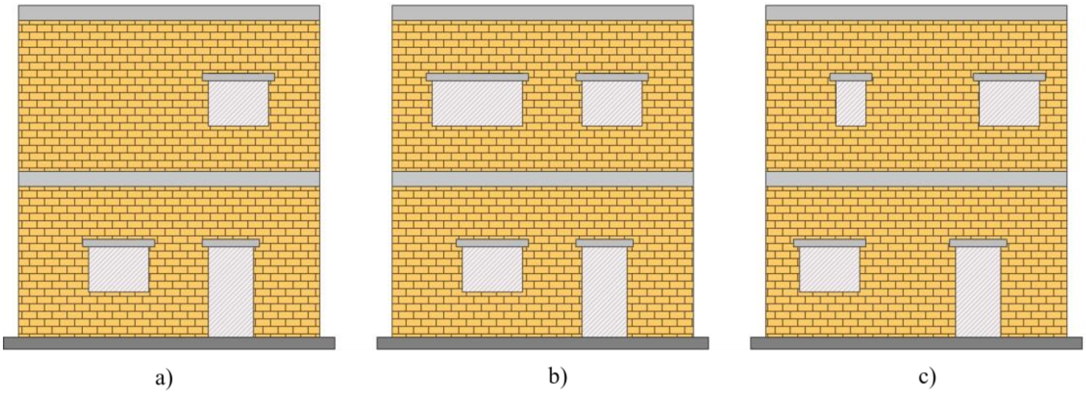


Figure 12. Examples of vertical irregularity in a building's structure, showing: a) a regular, b) a less irregular, and c) an irregular layout

It is determined whether different facades of a building have varying numbers of stories, as illustrated in Figure 13.

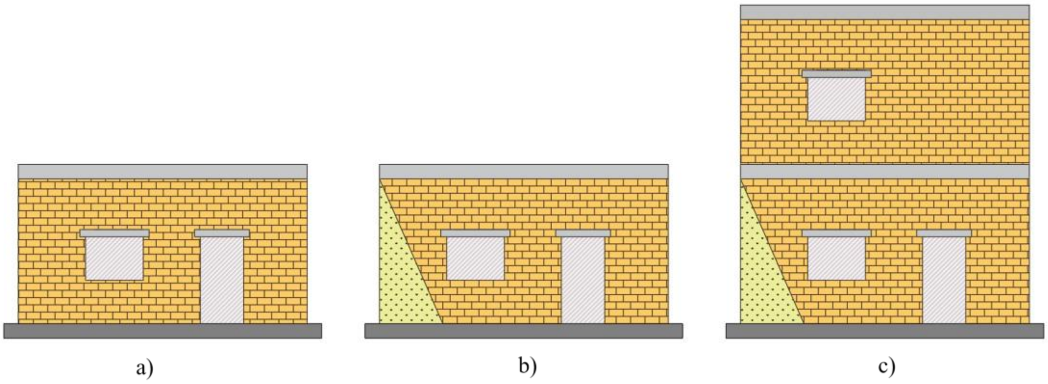


Figure 13. Floor-level variations observed on the facade, showing: a) none, b) available, and c) available

The presence of a soft or weak story is determined through observation, considering both the apparent differences in stiffness and height between floors, as shown in Figure 14.

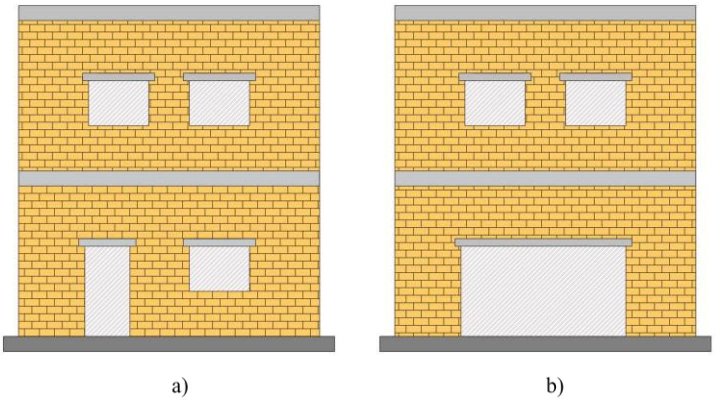


Figure 14. The presence of a soft or weak story, showing: a) none, and b) present

4.4. Other Rapid Assessment Methods

The previous sections provided a detailed examination of three rapid visual screening methodologies: the FEMA P-154 [48] procedure, considered one of the earliest and most influential frameworks in the field, as well as the Canadian [49] and Turkish [52] methods, both of which were applied in the present study. While these approaches offer structured and calibrated procedures for seismic risk assessment, numerous other countries have developed RVS systems tailored to their own building stock, seismicity, and regulatory contexts.

4.4.1. Japanese Methodology

The Japanese RVS methodology [53, 54], developed by the Japan Building Disaster Prevention Association in response to the 1968 Tokachi-oki earthquake [41], consists of a three-stage seismic screening process designed to assess the earthquake resilience of reinforced concrete buildings. The three levels of assessment include: preliminary screening, which involves a visual inspection focusing on material properties, cross-sectional dimensions, and general structural integrity; intermediate screening, a more detailed evaluation that includes ultimate load capacity estimation of key structural components; and detailed assessment, involving advanced testing such as material sampling and in-depth structural analysis [55]. Unlike simpler screening methods, this approach evaluates both structural and non-structural elements, with an emphasis on estimating the shear capacity estimation of columns and walls. The seismic index of structure (IS) is calculated based on structural parameters such as global shear strength, material properties, structural deformation and cracking.

The IS index is calculated using the following formula:

$$IS = E_0 \cdot SD \cdot T \tag{8}$$

where E_0 represents the basic seismic index, i.e., the fundamental seismic strength of the building, primarily determined by the shear capacity of structural elements. SD represents the irregularity index, which accounts for asymmetry and torsional effects, while T is the time index, reflecting material degradation over time. On the other hand, the seismic demand index, IS_0 represents the minimum required seismic performance level that building must satisfy to be considered safe.

$$IS_0 = ES \cdot Z \cdot G \cdot U \tag{9}$$

where ES is the basic structural demand index, representing a seismic demand value derived from observations from past earthquakes. Z denotes the seismic zone index. G represents the ground condition index. U is the usage index, reflecting the building's occupancy type. The seismic index IS is then compared to the seismic demand index IS_0; if $IS \geq IS_0$, the building is considered adequate in terms of seismic resistance; if $IS < IS_0$, the building is deemed seismically vulnerable and requires further assessment or retrofitting. Due to its comprehensive nature, this approach is more time-consuming than FEMA P-154. Still, it provides a more accurate evaluation of seismic vulnerability, which is particulary relevant for high-risk seismic regions.

4.4.2. Greek Methodology

The Greek rapid visual screening (RVS) methodology, known as OASP-0, was developed by the Earthquake Planning and Protection Organization [56, 57] in 2000 and is based on the first edition of FEMA 154 [48]. The method establishes a uniform rapid visual screening approach to determine a building's primary lateral-force-resisting system and construction materials. Each building is classified into one of 18 structural categories and assigned an initial structural hazard rating. This rating is subsequently adjusted to account for the seismic zone and three critical structural features: the presence of a weak story, short columns, and the regularity of masonry patterns. The resulting value, referred to as the basic structural hazard score, is further refined using performance-related attributes to produce the final score. Buildings with a final score of 2.0 or less are considered potentially vulnerable and therefore require a more detailed evaluation. To address the uncertainties associated with the score modifiers, two alternative scoring methods have been proposed: OASP-R, which improves upon the original system, and FEMA-G, based on the second edition of FEMA 154.

4.4.3. New Zealand Methodology

The New Zealand RVS methodology [58], developed in 1996 by the New Zealand Society for Earthquake Engineering [59, 60] is based on FEMA 154 [48] but adapted to New Zealand-specific building types, materials, and seismic risks. It primarily focuses on buildings constructed before 1975 which may not meet modern seismic standards. The NZSEE method utilizes a two-stage assessment framework. The initial assessment procedure serves as a preliminary screening, evaluating structural characteristics, design standards, retrofitting history, and seismic hazard factors. Detailed seismic assessment constitutes a more in-depth evaluation, applied to buildings identified as potentially earthquake-prone, in order to assess their compliance with the new building standards. A building's seismic performance is expressed through the new building standard (NBS) score, which incorporates parameters such as construction year, soil type, fault proximity, and structural irregularities.

$$\%NBS = (\text{Ultimate seismic capacity} \ / \ ULS \text{ seismic demand}) \times 100 \tag{10}$$

where the ultimate seismic capacity is based on the primary lateral-load-carrying system, while ULS represents the seismic demand in terms of ultimate limit states. Buildings are classified according to their %NBS score, which reflects seismic performance relative to a new code-compliant building. Scores of 33% or less indicate high vulnerability and the need for a detailed assessment. Scores ranging from 34% to 66% suggest moderate risk, while those between 67% and 100% indicate lower risk but may still require review. Values exceeding 100% reflect enhanced seismic performance.

4.4.4. Indian Methodology

The rapid visual screening procedure used in India is based on the FEMA 2002 methodology, with appropriate modifications for local conditions [61]. The Indian rapid visual screening methodology [62], developed by IIT Bombay as part of a national policy for seismic vulnerability assessment, provides a multi-tiered framework for evaluating buildings. The Level 1 procedure involves a walk-around inspection aimed at identifying the primary lateral load-resisting system and key building attributes influencing seismic performance. This assessment utilizes a scoring approach compatible with GIS integration. It is designed to take approximately 30 minutes per building and does not require structural calculations. Buildings are assigned to vulnerability classes (A–F) based on EMS-98 [25], and final scores (S) are interpreted using defined thresholds, with $S < 0.7$ indicating high vulnerability and the need for further assessment. The methodology includes 10 common building types, excluding very weak typologies with known poor performance, and adapts the FEMA-based scoring system to Indian seismic zones (II–V) and soil conditions. Higher-level procedures (Levels 2 and 3) incorporate simplified analysis or detailed computer modelling, respectively, and are recommended for critical or high-occupancy buildings.

4.5. Comparison of Rapid Assessment Methods

In recent decades, a wide range of rapid visual screening methodologies have been developed worldwide with the primary aim of quickly identifying seismically vulnerable buildings, especially in large building stocks, some of which have been presented earlier in this paper. Although these methods vary in structure, scoring logic, and application context, they share the common goal of providing a time-efficient, cost-effective, and reasonably reliable first-stage assessment that enables the prioritization of more detailed evaluations or retrofitting measures. Through this comparison, the aim is to highlight both the harmonized aspects and distinctive features of these methods, thereby providing a clearer understanding of their applicability across different regional or seismic contexts. Following the general classification of RVS methods, Table 18 compares the selected methodologies applied in this study with respect to several key assessment parameters. These include considerations of structural irregularity, local soil conditions, seismic hazard, and whether both structural and non-structural elements are incorporated.

Table 18. Comparison of parameters in selected RVS methods

Parameter	FEMA [48]	NRCC [49]	TR-R [52]	JDPA [54]	OASP [57]	NZSEE [58]	IIT-R [62]
Soil type	✓	✓	✓	✗	✓	✓	✓
Site seismicity	✓	✓	✓	✓	✓	✓	✓
Structural type	✓	✓	✓	✓	✓	✓	✓
Construction year	✓	✓	✗	✓	✓	✓	✓
No. of story	✓	✓	✓	✓	✓	✗	✓
Plan irregularity	✓	✓	✓	✓	✓	✓	✓
Vert. irregularity	✓	✓	✓	✓	✓	✓	✓
Short columns	✓	✓	✗	✗	✓	✓	✗
Weak/soft story	✓	✓	✓	✗	✓	✗	✓
Pounding hazard	✓	✓	✓	✗	✓	✓	✗
Occupancy	✓	✓	✗	✓	✗	✓	✓
Current condition	✓	✗	✓	✗	✓	✗	✓
Falling hazard	✓	✓	✗	✗	✗	✗	✓
Material quality	✗	✗	✓	✗	✗	✗	✗
Workmanship	✗	✗	✓	✗	✗	✗	✗
Wall amount	✗	✗	✓	✗	✗	✗	✗
Lintel presence	✗	✗	✓	✗	✗	✗	✗

Most RVS methods rely on sidewalk surveys, where trained inspectors assess visual indicators of vulnerability without intrusive testing or detailed calculations. Common parameters evaluated across different methodologies include structural system typology, plan and vertical regularity, soil conditions, number of stories, and the presence of specific deficiencies such as soft stories or short columns. Many rapid visual screening (RVS) methodologies also consider the local seismic hazard as well as the building's age or construction code level. Despite sharing similar objectives and core assessment criteria, significant differences exist in how these parameters are quantified, weighted, and incorporated into scoring systems. Additionally, visual condition assessment and the treatment of nonstructural elements are conducted with varying levels of detail, reflecting both regional priorities and the availability of data.

As noted previously, this study applies two methods, the Canadian and Turkish methods, to the same dataset of buildings. These two methods were selected due to their prominence in literature and because they have not yet been directly compared. As emphasized earlier, the reliability of these methods and their results critically depends on the quality of the screening process and the input data. The two selected methods were chosen based on their effectiveness and compatibility with the available data, making them the most suitable options for this study. It is highly recommended that future research further investigates and compares additional methodologies, which could ultimately contribute to developing a unified rapid seismic vulnerability assessment method adaptable to the Croatian building typology.

5. Building Database Overview

The structural characteristics of the buildings were defined as precisely as possible. However, it is important to note that completely accurate determination is not always feasible. Nevertheless, by reviewing available technical documentation, conducting field surveys, and utilizing data from the State Geodetic Administration of Croatia's website [63], a comprehensive database was created to classify and analyze the observed buildings. For the purposes of further comparison of rapid visual screening (RVS) methods, two streets in the city of Osijek were selected: Vukovarska, and Zagrebačka Street. Since Vukovarska Street gradually developed by connecting Gornji and Donji Grad, it encompasses buildings from various construction periods, ranging from the Austro-Hungarian Monarchy era to the Socialist period, approximately from the 1910s to the 1980s, as illustrated in Figure 15.

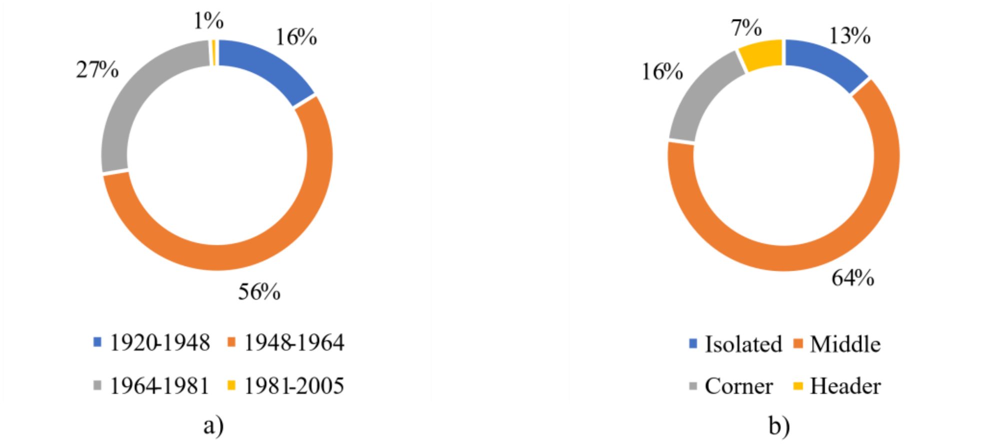


Figure 15. Distribution of: a) building construction periods, b) building position within a block

As illustrated in the figure above, the construction period from 1948 to 1964 predominates, comprising 56% of the buildings. Given that both streets are long and lined with buildings, it is expected that approximately 64% of the buildings occupy intermediate positions within the blocks. Regarding the occupancy and usage categories of individual buildings, it is evident that residential buildings constitute a significant share, along with mixed-use residential and commercial buildings. This distribution is to be expected, given that these streets are among the busiest and most vibrant in Osijek. In Figure 16, the distribution of buildings by their intended use, and level of maintenance is presented. It should be noted that the assessment of preservation status is highly subjective. However, this study has endeavored to evaluate the condition based on its impact on structural elements and the potential for adverse building behavior resulting from poor maintenance.

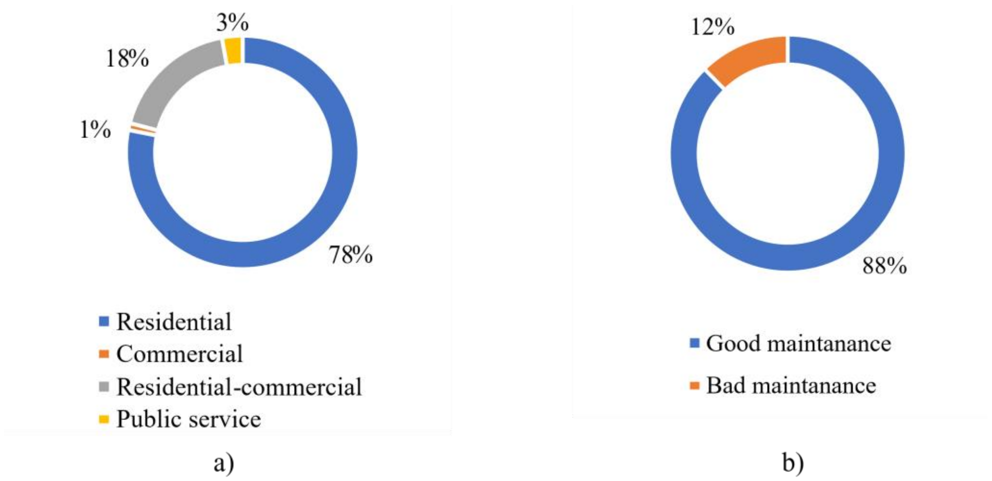


Figure 16. Distribution of: a) building purpose type, b) building maintenance condition

Although the previously mentioned factors are essential for a detailed analysis of buildings using the RVS method, where key parameters include the year of construction reflecting applicable laws and regulations and purpose (occupancy and its importance in the post-earthquake state), the following section focuses on the most critical aspects for assessing seismic vulnerability and risk. The structural system and regularity of buildings illustrated in Figure 17.

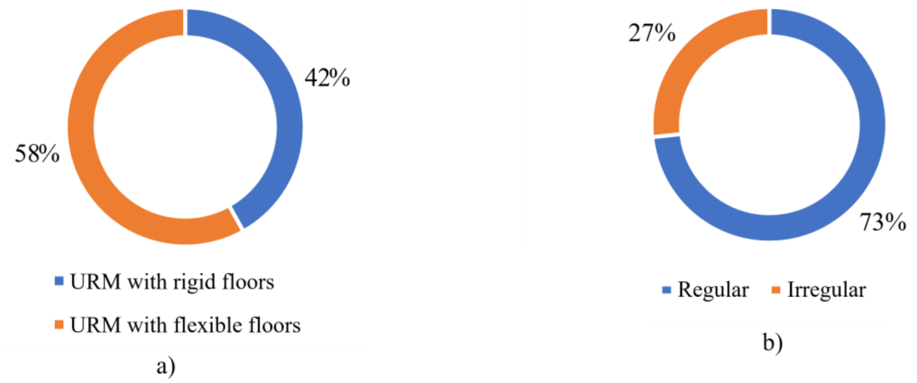


Figure 17. Distribution of: a) building structural system type, b) regularity of building

Another important parameter, also included in the Canadian RVS method, is the regularity or irregularity of buildings. Since most buildings are located mid-block, regular floor plans are the most common, comprising nearly 73%. Irregularities predominantly occur in corner buildings, whereas all buildings exhibit regular heights. The number of floors ranges from one to seven stories. However, most buildings fall into the following categories: one-story buildings (with the ground floor counted as a story) constitute 23%, two-story buildings 37%, three-story buildings18%, and four-story buildings 12%. Floor heights vary depending on the construction period of the buildings. Older buildings often feature significantly higher floor heights, sometimes reaching up to 4 meters, whereas relatively newer buildings typically have floor heights around 2.5 meters. Thus, the average floor height can be estimated at approximately 3 meters. After determining all the necessary characteristics of each building individually, the next step involves defining the structural and non-structural indices, which together contribute to the final seismic priority index for each building. The results of this analysis are presented in the following chapter.

6. Results and Discussion

After collecting and processing data for the observed buildings, both the Canadian and Turkish methods were applied to the same dataset, with seismic zones and regions selected according to the expected ground ace leration in the area, ensuring a context-specific assessment. Based on the previous statement, the comparison was limited to Seismic Zones 3 and 5 in the Canadian RVS method—corresponding approximately to 0.11g and 0.23g, respectively—and to Regions IV and II–III in the Turkish RVS method, which correspond to ground acceleration values of less than 0.2g and between 0.2g and 0.4g, respectively. As a result of applying the Canadian RVS method, a seismic priority index was calculated for each individual building as presented in Figure 18. For ground acceleration corresponding to seismic zone 3, most buildings fall into the low-priority category, comprising 57% of the total. Medium-priority buildings make up 42%, while high-priority and very high-risk buildings are nearly absent, accounting for only 1%. This distribution suggests that, under moderate seismic conditions, most buildings do not require immediate intervention. For ground acceleration corresponding to seismic zone 5, the results change significantly. The proportion of low-priority buildings decreases to 27%, while medium-priority buildings remain the largest group at 33%. However, high-priority buildings increase notably to 31%, indicating a substantial number of structures requiring urgent assessment. Additionally, very high-risk buildings, absent at lower ground accelerations, appear in this scenario, representing 9% of the total.

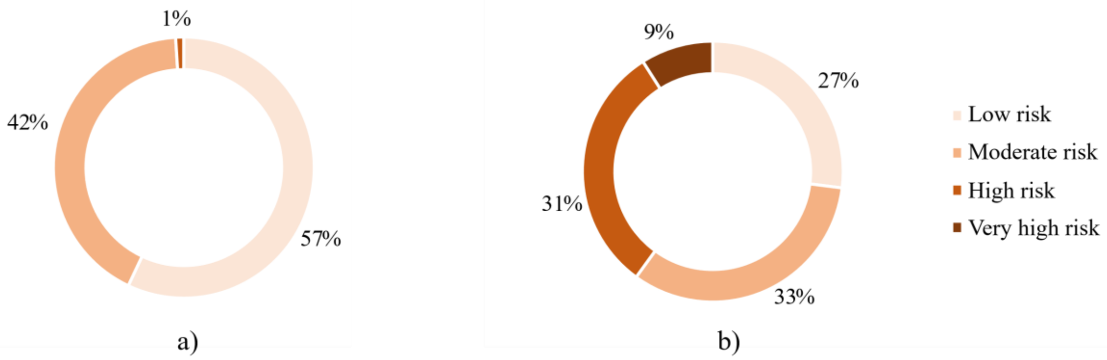


Figure 18. Distribution of seismic priority index for ground acceleration: a) 0.11g, b) 0.23g, expressed as a percentage of the total number of buildings

As a result of applying the Turkish RVS method, presented in Figure 19, for the lower ground acceleration level (<0.2g), the average performance score was 106, with a minimum of 50 and a maximum of 130. Of the buildings assessed, 47% scored below this average, while 53% scored above. For the higher acceleration range (0.2g–0.4g), the average score decreased to 96, with a minimum of 40 and a maximum of 120. The proportion of buildings scoring below average increased significantly to 78%, indicating a noticeable decline in structural capacity as ground acceleration rises.

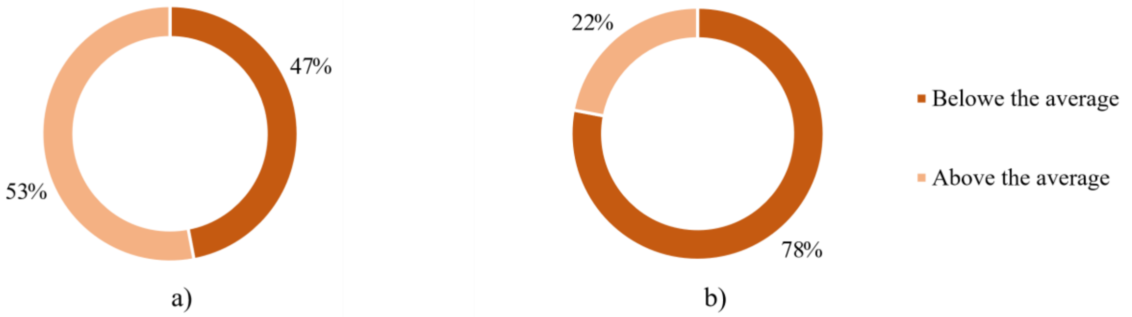


Figure 19. Distribution of buildings based on performance score in relation to average values, under different ground acceleration levels: a) <0.2g, b) 0.2g-0.4g

A significant limitation of rapid building assessment methods and various scoring systems is the difficulty, if not impossibility, of correlating their results. This challenge does not arise with more detailed analytical methods, which rely less on a wide range of empirical parameters, and are less dependent on the subjectivity of the assessor, provided the assessor is properly trained. Nevertheless, some conclusions can be drawn from the obtained results, which are more clearly illustrated through their graphical representation, as presented in the figures below.

To complement the numerical results presented on the previous page, the following visualizations provide a spatial representation of the seismic risk distribution across the surveyed area. The maps illustrate the classification of individual buildings based on their priority level under high seismic hazard conditions, as determined using both the Canadian, presented in Figure 20, and Turkish RVS method, presented in Figure 21.

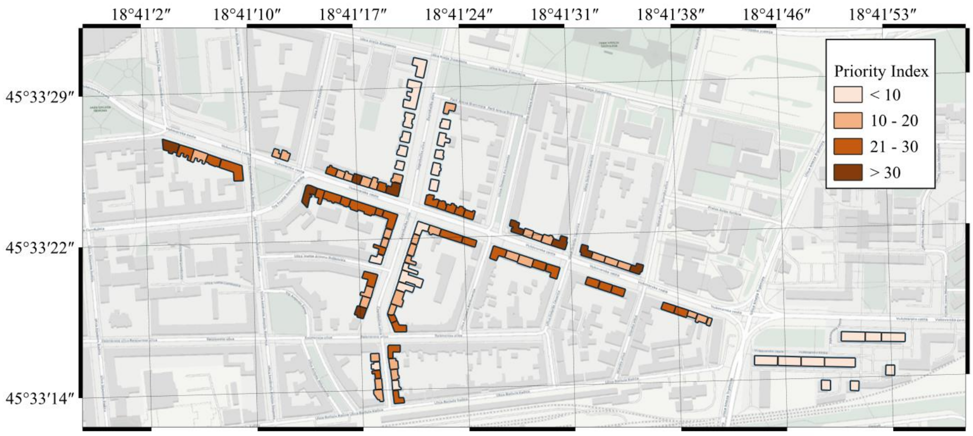


Figure 20. Classification of surveyed buildings according to the Canadian RVS method (for 0.23g), with priority index levels

Figure 21. Classification of surveyed buildings according to the Turkish RVS method (for 0.2g-0.4g), where performance scores are shown with respect to their average value

Both methods converge in identifying high-rise residential buildings as particularly vulnerable, which is especially relevant due to the typically higher occupancy rates associated with such structures. This agreement reinforces the reliability of both approaches in flagging critical cases that may require detailed assessment or immediate intervention. As highlighted in Figures 20 and 21, certain inconsistencies can be observed in specific instances. For example, a building may be classified as low-priority by the Canadian method, whereas its performance score according to the Turkish method falls below the average value. Such discrepancies can be attributed to the fact that the Turkish method incorporates a broader set of detailed parameters—such as wall condition, workmanship, and specific irregularities—making it more sensitive to certain structural vulnerabilities that the Canadian method may generalize. One limitation of the Turkish method is its restriction on the number of floors, as illustrated in the figures above, where the method could not be applied to buildings with more than five floors. Conversely, the Canadian RVS method provides a more granular classification of risk, offering a tiered scoring system with defined seismic priority index intervals, in contrast to the Turkish method's simpler binary categorization based on whether a structure performs above or below the average.

7. Conclusion

The current research adopts a comparative theoretical approach based on the principles of rapid visual screening methodologies, widely accepted as practical tools for prioritizing seismic risk in large building stocks. This study utilizes two distinct RVS frameworks to the same dataset of 105 unreinforced masonry buildings in Osijek: the Canadian method, which employs a multiplicative scoring system based on structural and non-structural indices, and the Turkish code-based method, which applies penalty-based deductions reflecting architectural and structural deficiencies. This theoretical framework enables a cross-method comparison that reveals how differences in parameter weighting and scoring logic affect risk prioritization outcomes. By situating the research within this dual method theoretical perspective, the study not only highlights the applicability of RVS in moderate seismic hazard regions but also advances the theoretical discourse on how international methodologies can be adapted, calibrated, and harmonized for local building typologies and seismic contexts. The theoretical foundation of this research lies in the comparative analysis of two rapid assessment approaches representing distinct conceptual frameworks. The Canadian methodology applies a multiplicative scoring system that integrates structural, geotechnical, and non-structural parameters into a Seismic Priority Index (SPI), thereby offering a comprehensive and continuous classification of seismic vulnerability across different building types. Conversely, the Turkish method employs a deductive, penalty-based approach, starting from a base score determined by seismic region and building height, which is then reduced according to observed deficiencies such as poor workmanship, irregularities, or pounding effects. This contrast highlights the theoretical difference between a holistic index-driven system and a field-oriented penalty system that is highly sensitive to construction quality. By applying both methods to the same dataset of 105 masonry buildings in Osijek, the study demonstrates how different theoretical logics influence risk prioritization and provides a framework for adapting international RVS methodologies to local seismic and construction contexts.

The results obtained from the application of the Canadian and Turkish rapid assessment methods provide valuable insights into the seismic vulnerability of Osijek's masonry building stock. A significant outcome of the comparative analysis is the consistent identification of mid- and high-rise masonry buildings as the most vulnerable, which is of particular concern due to their higher occupancy rates and the associated potential for greater human and economic losses. Moreover, the comparative interpretation reveals that the Canadian method is advantageous in providing a broader prioritization spectrum suitable for large-scale decision-making, whereas the Turkish method offers more detailed insights into specific weaknesses, such as workmanship quality and plan irregularities, that directly affect seismic performance. These findings underline the importance of using complementary methodologies in urban risk management, as their combined application offers the reliability of risk prioritization and provides a more comprehensive basis for planning retrofitting strategies, allocating resources, and developing seismic resilience policies for historic urban areas. This alignment suggests that, when applied to a uniform dataset and a relatively homogenous building typology, both methods are robust in capturing the key aspects of seismic vulnerability. Certain discrepancies observed in individual rankings can be attributed to the distinct weighting of parameters such as workmanship quality or plan irregularity, which are treated more explicitly in the Turkish method.

However, these differences did not significantly affect the overall risk classification, nor the identification of the most critical structures. This study also reinforces the broader importance of rapid assessment tools as cost-effective decision-support instruments for seismic risk management. When combined with field data, expert judgment, and urban planning needs, RVS methods provide a practical basis for prioritizing retrofitting efforts and enhancing urban resilience. Although certain analyses and results from surrounding countries could be applied to Croatian building typologies, it is important to note the significant internal diversity of typologies within Croatia itself. Specifically, the building typology of continental Croatia aligns more closely with Central European typologies due to a shared historical building culture, a similarity that does not extend to the coastal region of Croatia. It is also important to note that, while the coastal region experiences even higher seismicity, the results from this study cannot be directly applied to these areas due to significantly different building typologies compared to those analyzed here. This does not imply that the methods themselves are inapplicable; rather, their use requires different parameters that account for the distinct seismicity and specific building typologies of the coastal areas. Currently, a unified methodology for seismic vulnerability assessment does not exist in Croatia. Furthermore, a comprehensive national database of buildings, which is essential for a standardized approach, is also not yet available. Therefore, the most practical next step for the research community is to continue comparing various methods to develop a robust, unified methodology specifically adapted to Croatian building typologies. Moreover, developing a harmonized national screening framework, informed by local construction practices and historical seismic performance, would enable a more systematic and reliable implementation of seismic risk reduction measures at the national level.

8. Declarations

8.1. Author Contributions

Conceptualization, J.R., E.I., and M.H.N.; methodology, J.R., E.I., and M.H.N.; writing—original draft preparation, J.R. and E.I.; writing—review and editing, J.R., E.I., and M.H.N.; visualization, J.R. and E.I. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

Publicly available datasets were analyzed in this study. This data can be found here: https://app.im4stem.eu/#/public-data?type=database-overview.

8.3. Funding

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8.4. Conflicts of Interest

The authors declare no conflict of interest.

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