Pioneering Seismic Risk Assessments in Bucharest

An Interactive Qualifying Project Proposal submitted to the faculty of

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1 Introduction

On average, earthquakes impact 3.5 million people every year, including 60,000 deaths (Kenny, 2009). The Balkans is one of the most earthquake-vulnerable regions in the world. In 1977, an earthquake in the Balkan region collapsed or heavily damaged 32,900 buildings, left 35,000 homeless families (Georgescu & Pomonis, 2008), and caused 2 billion USD in damages (Craifaleanu et al., 2016). Although much of the world is developing earthquake resistant infrastructures (Dolce et al., 2021), some countries lag behind in earthquake preparedness and assessments. A shortage of experts and financial backing does not allow for sufficient building assessment, causing an inability to repair buildings after earthquakes in the Balkan region (Santoro et al., 2020). Out of the several countries that the earthquake affected, it devastated one country in particular: Romania.

Since 1471, a 7.0 magnitude earthquake has shaken Romania nearly every 80 years (Radulescu, 2008), including a magnitude 7.7 earthquake in 1940 and a 7.4 earthquake in 1977. With almost 50 years since the last 7.0 magnitude earthquake in Romania, experts predict that the next major earthquake will occur within the next half-century (Pavel & Vacareanu, 2017). Despite the seismic threat, Romanian buildings remain vulnerable to collapse (Armaş, 2006; Pavel et al., 2017).

Prior to the 1940 earthquake, the Romanian government had not created building codes to prevent buildings from collapsing. During the communist regime, Romania adopted building codes from Russia, endangering thousands of lives by encouraging unsafe structures, as engineers did not design these codes for Romania’s earthquakes which occur much deeper in the ground (Benevedes et al., 2021). After the 1977 earthquake, the communist regime resorted to cosmetic fixes rather than investing the time and money needed to fix structural deficiencies. As of 2017, 40,000 of 132,000 (30%) of Bucharest's residential buildings that endured the 1940 earthquake still house people today, meaning those people are at high risk. The Romanian government and building owners allow thousands of people to live in buildings without sufficiently addressing structural deficiencies following damages from the earthquakes (Armaş et al., 2017).

Although vulnerable buildings plague Romania, assessors have yet to inspect most structures. Since these assessments can lead to a decrease in property value and temporary homelessness for residents, both building owners and residents are reluctant to assess their buildings (Gillet, 2014; Suditu et al., 2020). Current assessment methods are also expensive and time consuming, as they require trained expertise (Suditu et al., 2020).

Since Bucharest is underprepared for earthquakes, nongovernmental organizations (NGOs) are helping Bucharest prepare. Re:Rise is an NGO that focuses on reducing seismic risk in Romania and is currently developing methods for rapid seismic risk assessments (RVSRAs). RVSRAs enable minimally trained assessors to inspect from sidewalks, allowing for assessments to be completed much faster (Applied Technology Council, 2016).

The goal of this project is to determine if rapid visual seismic risk assessments can predict building collapse to assist Re:Rise in populating a map of seismic vulnerabilities in Bucharest.

We plan to achieve this goal through three main objectives:

1. Evaluate seismic risk assessment methods.
2. Conduct rapid visual seismic risk assessments.
3. Determine the relevance of rapid visual seismic risk assessments.

The team plans to utilize expert interviews to gain insight on how to adapt RVSRAs to Romania. A member of Re:Rise will train the team in conducting RVSRAs. After the training, the team will adjust the process for RVSRAs based on recommendations from the interviews. Then the team will conduct RVSRAs. After gathering the data, the team will perform both quantitative and qualitative analysis to gather results which will be delivered to Re:Rise. The team will input the results into Re:Rise's map of seismic vulnerabilities and deliver a set of recommendations to improve the RVSRA training process and the assessment process itself.

2 Background

Earthquakes occur when large sections of earth release built up pressure in the form of a burst of energy and travel through the earth in the form of a seismic wave. Although large earthquakes cause building collapse, proper design and construction can mitigate this risk. The background chapter begins with an overview of the impacts and history of earthquakes in Romania. Then, the next section examines the impact the Romanian government has on the seismic vulnerability of buildings. This chapter closes by discussing seismic risk assessment (SRA) methods. A table of commonly used abbreviations is found in Appendix A.

2.1 Seismic History of Romania

Numerous historical accounts record the long history of earthquakes, such as the 1802 earthquake known as “The Big Earthquake of God’s Friday,” which reached a magnitude of 7.7 and devastated Romanian buildings, like the Tower of Colţea (see Figure 2.1a and 2.1b) (Radulescu, 2008).

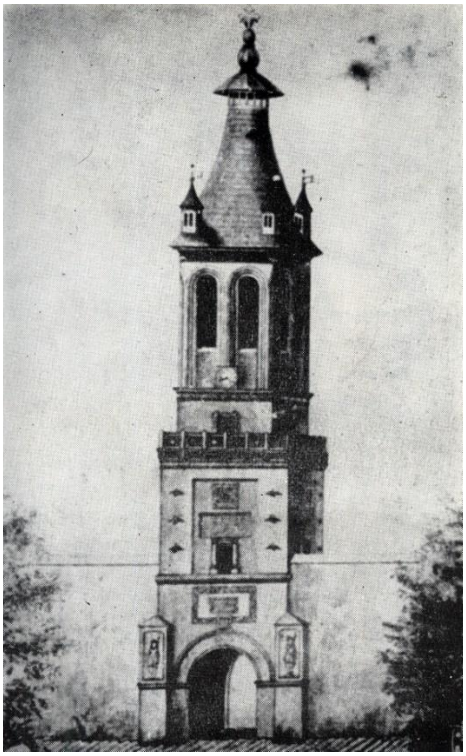

Figure 2.1a, – Ready To Be Toppled –
The Coltea Tower prior to the Vrancea Earthquake of 1802

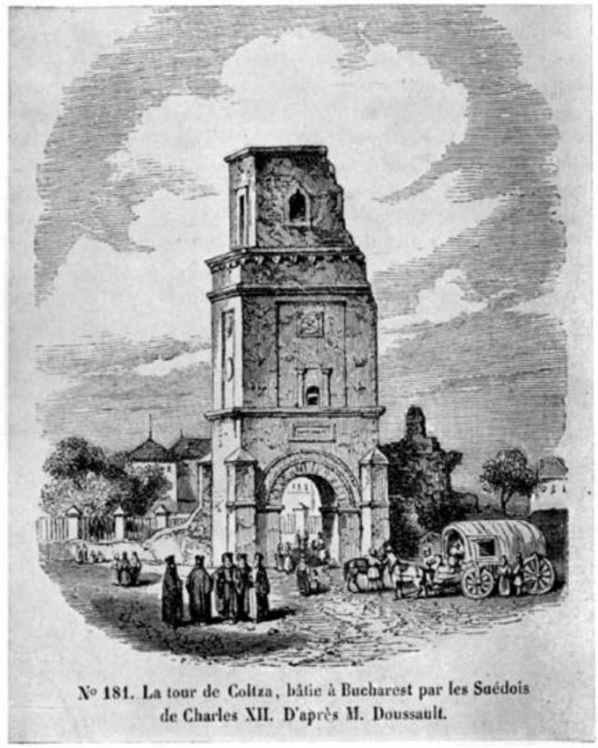

Figure 2.1b, – The Mighty Have Fallen –
Tower of Colțea after 1802 earthquake

With smaller population centers and the only tall structures being churches, historical earthquakes took few Romanian lives. This changed in the twentieth century, when two major earthquakes devastated the newly industrialized and densely packed city. The first occurred on November 10th, 1940, producing a 7.7 magnitude earthquake, which caused an estimated 1,000 deaths and an additional 11,000 injuries (Lungu et al., 2008; Pavel & Vacareanu, 2017). A second earthquake of 7.4 in magnitude struck on March 4th, 1977, killing 1,578 people and injuring 11,221 people, most of whom resided in Bucharest (Georgescu & Pomonis, 2012). Additionally, the World Bank valued the economic damage at $2.05 billion USD (Lungu et al., 2008). The earthquake's devastation sparked a new era of academic research and public effort towards earthquake preparedness (Mândrescu et al., 2007).

The Vrancea region is the area responsible for over 90% of Romania's earthquakes (Lungu et al., 2008; Poiata & Miyake, 2017). The region is located 135 km northeast of Bucharest and produces earthquakes ranging from 5.0 to 8.0 in magnitude (Radulescu, 2008). Unlike seismic zones forming from tectonic plates, causes of Vrancea's seismic activity are still unknown. Current seismology measurements place the average epicenter within the Vrancea region at 60 – 200 km below the surface (Poiata & Miyake, 2017). The intermediate-depth of the seismic source enables the earthquakes to travel large distances and damage taller buildings (Mândrescu et al., 2007). Earthquakes of different depths will impact Earth's surface differently. To determine the level of vulnerability within Romania, seismologists developed predictive models to illustrate seismic activity in Bucharest and updated seismic codes. One such study produced a map of Bucharest depicting the expected damage of an earthquake equivalent to that experienced in 1977 (see Figure 2.2). The Medvedev–Sponheuer–Karnik Scale (MSK) gives the scale of the damage (Mândrescu et al., 2007). The darker the color and the higher the roman numeral, the more severe the damage. VII corresponds to older buildings collapsing and VIII corresponds to large cracks and fissures opening on the surface. Appendix B: Medvedev–Sponheuer–Karnik Scale provides a description of the MSK scale.

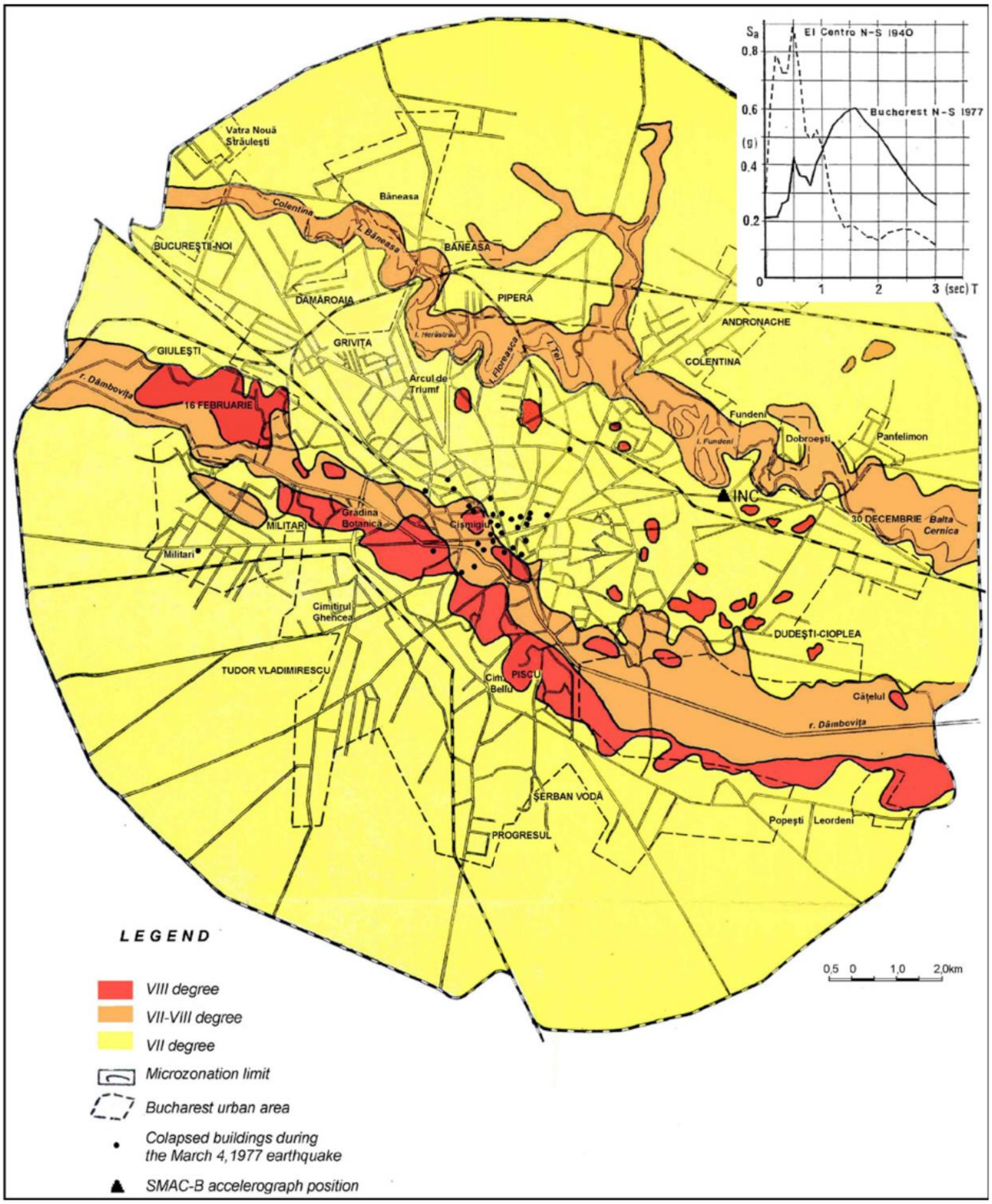

Figure 2.2 Seismic microzonation map of Bucharest (STAS 8879/6-73)

Furthermore, computer simulations have predicted inadequacies in current seismic assessment codes. In simulations, many of the buildings that pass current building codes collapse. If the simulations are accurate, the seismic codes mislead hundreds of thousands of Romanians to believe they are safe from the next major earthquake when they are not (Pavel &

Vacareanu, 2017). With almost 50 years since the last magnitude 7.0 earthquake in Romania, experts expect the next major earthquake to occur within the next 50 years (Pavel & Vacareanu, 2017).

2.2 Romanian Government's Impact on Earthquake Vulnerability

In addition to the dangers the Vrancea seismic zone poses to the Romanian public, the government has hindered Romania's earthquake preparedness. During the communist regime, insufficient building codes, poor urban planning, and a lack of repairs to damaged buildings left Bucharest highly vulnerable to earthquakes (Armaş, 2006; Benevedes et al., 2021; Mungiu-Pippidi, 2010). Although building codes improved afterwards, builders seldom followed them and corruption plagued the construction industry (Georgescu & Pomonis, 2012).

2.2.1 History of Communism in Romania

In 1948, a communist government took over Romania. The government implemented Stalinist principles of rigid central planning and an emphasis on heavy industry (Communist Romania, n.d.). This led to an increase in large state-owned buildings, such as factories, apartment complexes and government buildings. In 1965, when Nicolae Ceausescu rose to power as elected president of Romania, he intensified the communist party's power, running the country as a dictator with a cult-like following (Communist Romania, n.d.).

Pushing for urbanization, Ceausescu devised a plan to reconstruct Romania which included demolishing and replacing 13,000 Romanian villages with large apartment complexes (Mungiu-Pippidi, 2010) to spread the benefits of urbanism and create sameness across Romania (Danta, 1993). Out of the 13,000 villages, the government demolished 10,000 of them immediately and planned to destroy the other 3,000 in the coming years, replacing them with apartments on the outskirts of Bucharest in 1975 (see Figure 2.3) (Mungiu-Pippidi, 2010).

Figure 2.3: Apartment buildings in systemized villages (Danta, 1993).

The government rushed apartment construction to house the newly homeless villagers. The increased housing demand led to Ceausescu constructing twice as many apartments as originally planned (Mungiu-Pippidi, 2010). To accommodate this change, construction moved at a “mad pace” causing infrastructure flaws (Mungiu-Pippidi, 2010). Ceausescu planned to heat the apartments using firewood stoves, which required apartments to be densely-packed (Mungiu-Pippidi, 2010). The government could not afford central heating or modern sewage systems which resulted in using the same water and sewage systems from villages in much more populous apartments (Mungiu-Pippidi, 2010). With such cheaply built mass housing, experts conclude that Ceausescu did not construct the apartments while considering seismic risk (Green, 2005). This increased the country’s earthquake vulnerability, since high-density buildings may damage each other upon collapse (Armaş, 2006), which occurred in the 1977 earthquake (Barnaure, 2021).

Even though buildings remained damaged or destroyed from the 1940 earthquake, Ceausescu had no plan to improve or reconstruct Bucharest's historical center (Armaş, 2006). The historical structures remain as a symbol of Ceausescu's failure to rebuild the city.

2.2.2 Corruption in Post-Communist Romania

After several years of changes and instability, Romania started preparing to join Europe, eventually joining the European Union (EU) in 2007. Following its entrance into the EU, Romania rolled back their anticorruption commitments that allowed EU entry in the first place, such as exempting the president, senators, and lawyers from corruption crimes like abuse of office and bribery (Toma, 2015). Additionally, the government reduced the power of prosecutors like the National Anticorruption Directorate – an independent agency dedicated to prevent, investigate and prosecute corruption related offenses – even threatening to shut it down (Toma, 2015).

Since laws protected politicians from corruption crimes, authorities used their power to corrupt government construction projects. Government leaders used a practice known as "single bidding" where the state awards contracts to private construction companies using a non-competitive procedure where only one company bids for a contract. Researchers found that 32% of the government-awarded construction contracts between 2007 – 2013 involved single-bidding or the existence of political connections, pocketing construction industry €200 million (Doroftei, 2016). Additionally, the analysis notes the National Anticorruption Directorate charged 54% of Romanian county council presidents with corruption from 2007 – 2013, including mayor of Bucharest Sorin Oprescu, who received prison time for taking bribes in exchange for public work contracts (Benevedes et al., 2021). Corruption within the construction industry often leads to defective or dangerous infrastructure (Sohail & Cavill, 2019). For instance, a government member may allow contractors to illegally build extra stories or violate building codes in exchange for a payoff (Green, 2005). Between 2007 and 2013, the government awarded 1,086 contracts to companies with political ties (Doroftei, 2016), meaning it is likely the construction companies did not abide by the building codes during construction, increasing the seismic vulnerability of these structures (Benevedes et al., 2021).

2.2.3 Romanian Government Building Code Failures

The Romanian government uses building codes to regulate building quality and earthquake vulnerability. Over the past 100 years, the government has made building codes more rigorous. Experts classify the codes into four distinct periods: pre-code, low-code, moderate-code, and high-code (see Table 2.1).

Table 2.1: Classification of codes for earthquake resistant design of buildings in Romania, (Vacareanu et al., 2004).

Period		Code for earthquake resistance of structures
Pre-code, before 1963	Prior to the 1940 earthquake and Prior to the 1963 code	P.I. - 1941 I - 1945
Low-code, 1963-1977	Inspired by the Russian seismic practice	P 13 - 63 P 13 - 70
Moderate-code, 1977–1990	After the great 1977 earthquake	P 100 - 78 P 100 - 81
Moderate-code to High-code, after 1990	After the 1986 and the 1990 earthquakes	P 100 - 90 P 100 - 92

During the pre-code period, authorities rarely enforced the very few policies that regulated structural quality, leading to the construction of vulnerable buildings (Armaş et al., 2017; Vacareanu et al., 2004). Figure 2.4 shows that Romanians constructed thousands of buildings in Bucharest before 1945 that still stand today.

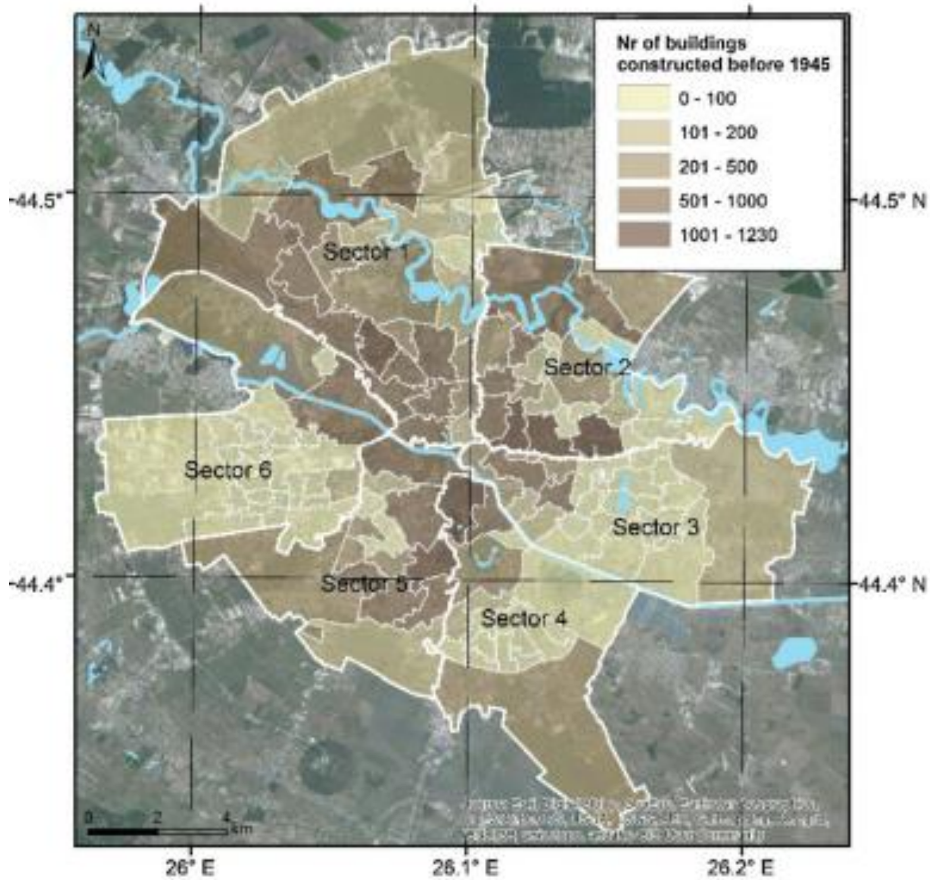

Figure 2.4 The number of buildings in Bucharest erected before 1945 (Armaş et al., 2017)

These buildings remain highly vulnerable to collapse, since they exhibit none of the design regulations that reduce seismic risk today. This proved dangerous in the 1940 earthquake, where a twelve-story structure called the Carlton Building collapsed (see Figure 2.5), killing 140 of 226 occupants and injuring 86 (Georgescu & Pomonis, 2012). Furthermore, in the 1977 earthquake, 19 high-rise apartment buildings from the pre-code era collapsed, contributing to a major portion of the casualties in Bucharest (Georgescu & Pomonis, 2012). This made it clear to the Romanian government that they needed to implement better codes to reduce seismic damage.

Figure 2.5: Carlton Block before collapse (left) and immediately after collapse (Georgescu & Pomonis, 2012).

The Romanian government first implemented low-code regulations, modeled after Russia’s 1960s building code system. Low-code introduced regulations for concrete and steel quality, as well as standards for structural beam sizes (Vacareanu et al., 2004). Additionally, the Romanian government adopted Russia’s strategy of mass urbanization. This style of urban planning did not consider the uniqueness of Romania’s earthquakes, which occur much deeper below the earth’s surface than Russian earthquakes (Benevedes et al., 2021). This causes qualitatively different outcomes. For instance, Romanian earthquakes tend to damage taller buildings more, while Russian earthquakes tend to damage smaller buildings (Armaş, 2006). This explains why high-rise buildings like the Carlton building are prone to collapse. Therefore, using a system modeled after Russia proved inadequate in regulating the structural stability of tall buildings in Romania.

After the damage from the 1977 earthquake revealed the inadequacies of low-code, the Romanian government tightened their regulations to moderate-code, which required reinforcement tests in structural columns. Following two smaller earthquakes in 1986 and 1990, the government further tightened the standard of these tests with the establishment of high-code in 1990. Both moderate-code and high-code demanded builders to use better quality and stronger concrete and steel. Although these newer codes have proven to significantly reduce the probability of a building's collapse, the Romanian government does not require owners to strengthen existing buildings from the pre-code and low-code period (Georgescu & Pomonis, 2012). In short, the Romanian government allows the 40,000 pre-code buildings, or 30 percent of all residential structures, to bypass current regulations, putting their inhabitants at risk (Armaş et al., 2017).

2.2.4 Post-earthquake Structural Vulnerabilities

Although building codes were strengthened after the earthquake in 1977, the disaster left critical structural damage. During the weeks following the earthquake, national engineers began assessing buildings with the most severe damage and recommended a more thorough assessment of all affected buildings. However, President Ceausescu ignored these recommendations and ordered for immediate repair of 14,000 damaged buildings in seven weeks (Simpson et al., 2020). Shortly after, seeing little progress and dwindling funds, Ceausescu ordered the stop of all repairs (Georgescu & Pomonis, 2011; Simpson et al., 2020), resulting in uncertainty of building vulnerability statuses. In their rush, builders strengthened some buildings, patched others cosmetically and did nothing to most (Barnaure, 2021; Simpson et al., 2020). Experts have described the attempted repairs and the uncertainty surrounding them as a "big mistake" and predict that half of Bucharest hospitals will collapse in the next earthquake as a result (Armaş, 2006; Lungu et al., 2000).

In a seismic vulnerability case study, Technical University of Civil Engineering Faculty member Mircea Barnaure analyzed an 11-story building built in 1962 (Barnaure, 2021). The building in question suffered major damages from the 1977 earthquake and smaller earthquakes in 1986 and 1990. An investigation report from 1993 mentioned cracks in the building's walls, beams, and lintels. Although another investigation report from 2020 mentioned none of these damages, this resulted from local repairs like the plastering of the shear walls with epoxy resin and fiberglass fabric, hiding the structural damages of the building (Barnaure, 2021). However, a seismic vulnerability analysis concluded that this building has only 20% of the required earthquake capacity loads, needing major strengthening to meet the 65% building code standard. Such findings are representative of similar buildings from the same time period. One source argues that 85% of the buildings with more than five stories in Bucharest still require strengthening from damage caused by the earthquake (Pavel et al., 2021). This amounts to 2,500 highly vulnerable buildings residential buildings that the government or building owners have not repaired (Pavel et al., 2021).

2.3 Romanian Earthquake Prevention and Preparation

The Romanian government developed the Romanian Code for Seismic Risk Assessment of Existing Buildings P100-3/2008 to determine the likelihood of a building to collapse during the next earthquake (Suditu et al., 2020). The Ministry of Public Works, Development and Administration (MPWDA) is responsible for building regulation and disaster risk management in Bucharest, including the enforcement of P100-3/2008. MPWDA-certified experts have identified about 2,400 buildings at risk of collapse (Suditu et al., 2020), which the Municipal

Administration for the Consolidation of Buildings with Seismic Risk then classified into four sub-groups shown in Table 2.2. Like most Romanian buildings, many of these buildings have a mixed ownership regime, consisting of private and state owners (Ivanov, 2021).

Table 2.2: Classification of buildings in Bucharest on their risk to collapse due to a seismic event (Ivanov, 2021).

Municipal Administration for the Consolidation of Buildings with Seismic Risk Classifications	
Class	Definition of Class
RsI	High risk to collapse
RsII	Likely to have major structural damage
RsIII	Likely to have major structural damage but do not impact structural safety
RsIV	Meet modern seismic risk standards

The Romanian government has marked buildings of classification RsI; buildings with the highest risk of collapse, with a red dot on the side of the building. As of 2021, 358 buildings in Bucharest have red dots (Ivanov, 2021), including 175 in a special category known as “public hazard”, which have four or more stories and commercial spaces on the ground floor (Ilie, 2017). From 2016-2020, owners and the Romanian government began the seismic reinforcement process of 12 of the 358 buildings. As of March, 2021, owners and the Romanian government made plans for reinforcements of 11 more buildings (Ivanov, 2021). These 23 buildings are still not complete and leave 335 assessed buildings that owners or the Romanian government need to reinforce, plus an additional 2,200 vulnerable buildings that experts have not yet assessed (Sumbasacu, 2022). At this rate engineers will not be able to repair all buildings before the next earthquake, leaving tens of thousands of lives in danger (*Re:Rise, Overview*, 2022).

The MPWDA created a twenty-year plan in 1996 to help track and reduce building's seismic risk for the future. Building owners, administrators, individuals, and owners' associations were responsible for hiring experts to inspect their buildings and update a technical charter, which included tracking the mechanical strength and stability of existing structures with insufficient levels of protection against earthquakes and classifying them in the proper seismic risk class. In 2018, two years after the twenty-year deadline, most private and public actors in this plan failed to document and complete these actions, increasing Bucharest's vulnerability (Suditu et al., 2020).

2.3.1 Obstacles to Current Building Assessment

The Romanian government refrains from doing assessments as they can be costly, intrusive, and lengthy. SRA's often involve inspectors to have unrestricted access to a structure over multiple days and high-tech equipment to process laboratory samples. Even with thousands of vulnerable buildings, building owners only requested seven assessments between 2000 and 2014 (Gillet, 2014). One reason for this is the potential that the assessment will yield a red dot, which decreases a building's property value. Most apartments in Bucharest are privately owned, meaning the owners do not wish for their individual apartment prices to drop (Ana, 2018). The current assessment, P100-3/2008, takes two weeks (M. Sumbasacu, personal communication, February 17, 2022) and needs trained professionals to enter the building to record a detailed description of the design of the building (Suditu et al., 2020).

Additionally, Edmond Niculușcă, the current city director, said "the lack of transparency, coherence, and predictability, has led to many of the repair projects being blocked" by the local government (Ivanov, 2021). The Romanian government supplies interest-free loans to residents wishing to conduct building repairs, but only if every resident within the building agrees to conduct repairs (Gillet, 2014). Public distrust of the government following the rise and fall of communism reduces the chance that residents cooperate with government programs. Determining the owner of a building is also difficult “as numerous properties were confiscated by the communist regime and the process of returning these properties to their previous owners is, a quarter of a century after the fall of communism, not yet complete” (Armaş et al., 2017). Additionally, many residents remain resistant to assessments and major repairs as finding alternate living can be costly and scarce, and the Romanian government does not have the available housing to help (Ivanov, 2021).

2.4 Analysis of Various Building Assessment Methods

Systemic issues have caused barriers in conducting SRAs under the current method, as they require unreasonable amounts of resources, such as time, money, and trained professionals. As a result, researchers and institutions have created alternative methods to combat these setbacks (Lupășteanu et al., 2021; Pardalopoulos et al., 2012). Each method has advantages and drawbacks, trading comprehensiveness for accessibility and timeliness.

2.4.1 Evaluating Time for Various Assessment Methods

With a rapid assessment method, engineers can speed up the SRA process. Assessors are looking to assess as many buildings as possible before the next earthquake and need a new tool to speed up the process. In an article published by the Journal of Building Engineering (JBE), engineers used a more streamlined method to document and inspected 90 buildings in 63 days, averaging 1.4 buildings a day (Lupășteanu et al., 2021). JBE’s method reduced average time from two weeks to 1.4 days by eliminating much of the process, such as sending the soil to the lab (Lupășteanu et al., 2021; M. Sumbasacu, personal communication, February 17, 2022). In the Bulletin of Earthquake Engineering (BEE), three Greek engineers published a different method, simplifying the inspection method, by focusing on pillars and walls, while ignoring additional major subsystems like roofing and plumbing (Lupăşteanu et al., 2021; Pardalopoulos et al., 2012). Alternatively, the United States' Federal Emergency Management Administration (FEMA) proposes a different method, called a rapid visual seismic risk assessment (RVSRA), that simplifies SRAs even further. FEMA's RVSRA takes between 15 and 75 minutes per building with assessors exclusively using visual methods and focusing only on obvious structural deficiencies as seen from a sidewalk (Applied Technology Council, 2016).

2.4.2 Additional Advantages of Rapid Visual Seismic Risk Assessments

RVSRAs further simplify the assessment process to allow quicker assessments. Although rapid SRAs, such as the JBE and BEE methods, reduce the time required for assessors to analyze structures (Lupăşteanu et al., 2021; Pardalopoulos et al., 2012), RVSRAs have the potential to tackle many of the underlying systemic issues plaguing seismic assessments in Bucharest (M. Sumbasacu, personal communication, February 17, 2022). For example, residents may block assessors from using the JBE and BEE methods, as they require assessors to access the interior of structures, while RVSRAs methods bypass this problem completely. Additionally, the Romanian government or building owner must pay civil engineers for traditional SRAs (Lupăşteanu et al., 2021; Pardalopoulos et al., 2012), while volunteers with no experience can conduct RVSRAs (Applied Technology Council, 2016). RVSRAs can be used to determine if further, more comprehensive, SRA methods should be used on high-risk buildings to fully understand their seismic vulnerabilities.

2.4.3 Process and Complexity

Each SRA method has its own process and level of complexity. The more complex an SRA, the longer it takes. Of these, the JBE has the most detail, as it examines all major subsystems of a structure (Lupășteanu et al., 2021). The BEE assessment specifically examines two major structural aspects. First, the BEE assessment focuses on pillars and weight distribution to analyze load bearing capacity. Next, it targets inter-story drift, where the upper level of a building offsets from the ground story. Moreover, this method requires complex mathematical calculations to determine structural integrity (Pardalopoulos et al., 2012). Finally, FEMA uses an all-visual method to look at obvious structural deficiencies, such as cracks or missing supports to determine whether a building will collapse during an earthquake, meaning assessors require more detailed SRAs to determine how to identify building strengthening opportunities (Applied Technology Council, 2016).

2.4.4 The Association for Seismic Risk Reduction (Re:Rise)

Romanian NGOs are taking action to reduce seismic risk in Romania. One of these NGOs, Re:Rise, aims to "act as a bridge between people at risk of seismic risk and … the technological, financial, administrative and human resources available" (Sumbasacu, 2022). Re:Rise's projects include a registry of construction vehicles and aerial photography methods to assist emergency services immediately following an earthquake. Additionally, Re:Rise maintains a map containing seismic information for individual buildings in Bucharest (see Figure 2.6).

Although Re:Rise has a publicly available seismic risk map, much of the necessary data is missing (M. Sumbasacu, personal communication, February 17, 2022). Orange highlights and red dots represent surveyed buildings. Purple lines indicate predicted road blockages. RVSRAs can help Re:Rise fill in the map, which will help both engineers and first responders. Engineers can use the map to determine which buildings should receive further inspection, prioritizing the most damaged structures. First responders can use the map to predict which roads' rubble will block in the event of an earthquake (M. Sumbasacu, personal communication, February 17, 2022). This will save lives as first responders will not only know from the map which places have the highest rates of building damage, but the map can also predict which routes will be blocked.

Figure 2.6 Re:Rise Map of Risk, accessible at dupacutremur.ro

Romania has faced a myriad of historical and social challenges that have inhibited its process to identify building vulnerabilities and begin repairing the damaged buildings. RVSRAs can help Romania start to reduce the risk when the next earthquake occurs. The team hopes to help populate Re:Rise's map and generate recommendations to improve RVSRAs.

3 Methodology

The goal of our project is to determine if rapid visual seismic risk assessments, (RVSRAs), can predict building collapse to assist Re:Rise in populating a map of seismic vulnerabilities in Bucharest. We plan to achieve this goal through three objectives.

- Evaluate seismic risk assessment methods
- Conduct rapid visual seismic risk assessments in Bucharest
- Determine the relevance of rapid visual seismic risk assessments

The team will complete these objectives from March 14th to May 3rd, 2022. The team outlined the objectives in Figure 3.1 below, matching methods to their corresponding objectives. This chapter explains the methods the team plans to use in accomplishing each objective.

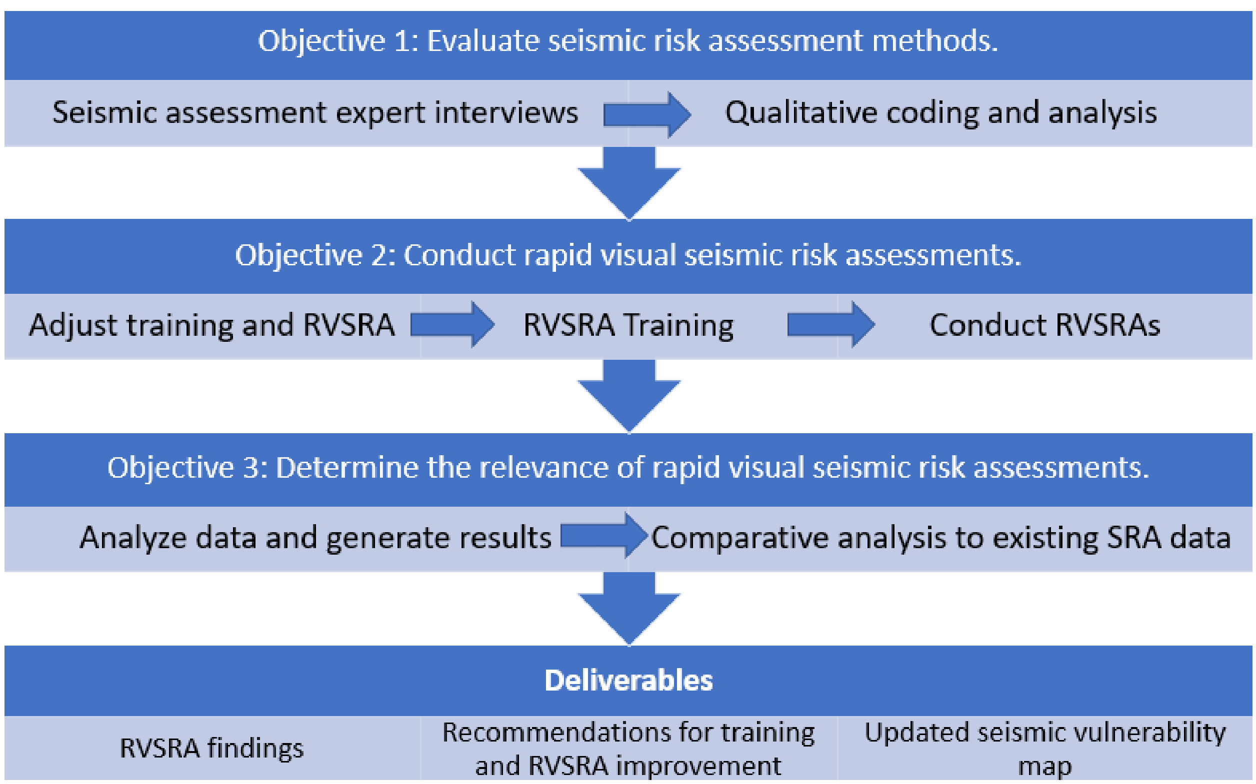

Figure 3.1: Methodology Overview for Project

3.1 Evaluate Seismic Risk Assessment Methods

This project intends to anticipate potential strengths and weaknesses in conducting SRAs, with a major focus on rapid visual seismic risk assessment methods. Performing expert interviews will prepare the team for expected challenges in executing RVSRAs and facilitate tailoring the RVSRA to Romania. Previously, assessors have only applied RVSRAs outside Romania. RVSRAs conducted in different countries encounter different building types. For instance, FEMA's RVSRA method focuses on single unit housing structures, while the team will adapt the RVSRA method to focus on large apartment complexes common in Bucharest. Furthermore, expert perspectives may also be valuable prior to assessing buildings, as experts potentially have experience categorizing building safety from RVSRAs.

The team will conduct interviews with leading experts on SRAs, including civil engineers and seismology researchers. To identify potential respondents, the team will utilize both Re:Rise industry connections within Romania and globally recognized seismic researchers. Collaborator Matei Sumbasacu, founder of Re:Rise, has years of seismic consulting experience and is a frequent contributor to the *New York Times* reporting on seismic vulnerability (M. Sumbasacu, personal communication, February 17, 2022). The team will leverage his connections and knowledge to identify and contact qualified industry experts using publicly available e-mail addresses. Additionally, the team can use authorship information from peer-reviewed articles to identify additional interview subjects.

This study plans to conduct the interviews from March 14th to March 23rd, 2022. The interviews will take place using Zoom, unless the respondent can meet in person, in which case the team and respondent can agree on an interview location. Each interview will have a primary interviewer and scribe. The primary interviewer will start the interview by reading the Interview

Confidentiality Statement (see Appendix C) and will request permission to use audio and video recordings for future reference.

Interviews will follow a semi-structured interview format. Semi-structured interviews give the interviewer freedom to explore additional stories or points of information not included in the prepared questions from the interview guide (see Appendix D). Although the team may add follow up questions for each interview session, the group will maintain common goals and keep broad interview topics consistent. This means that the interviewer will cover each broad topic and the interviewer may follow up with questions in areas that the interview subject has expertise. For example, an interviewer may ask different follow up questions to an expert in Turkey compared to one from the United States. Questions will focus on the respondents' experiences with RVSRAs and common impediments when implementing them.

The team will use qualitative coding to interpret, organize, and structure observations to identify main themes and insights from the interviews. The qualitative coding will include both deductive and inductive coding. This allows the team to anticipate the main themes that will emerge from the interviews while maintaining room for exploratory research since experts may speak about themes the team did not anticipate. The two main themes the team will focus on are traits of SRAs and items recorded during SRAs. The team chose these themes to compare the aspects of traditional SRAs to RVSRAs. These themes include subcategories that will help the team understand what experts believe are most important to a successful RVSRA method in their general experience and in Bucharest specifically (see Appendix E). The experts may mention additional items that would be appropriate to add as subcategories accordingly, as well as larger overarching themes that the team will need to analyze.

3.2 Conduct Rapid Visual Seismic Risk Assessments

To understand the capabilities and challenges associated with adapting RVSRAs to Bucharest, the team will participate in a pilot program by Re:Rise to begin using RVSRAs. As part of the pilot program, the team will take a six-hour assessment training course to learn the skills to conduct RVSRAs. During the training, the team will learn how to identify seismic cracking and other elements of building pathology, how to approximate construction period of a building based on architectural style, and basic aspects of seismic design for buildings. The findings from completing objective 1 will influence the initial RVSRAs by including tips to avoid obstacles that experts have experienced when conducting SRAs.

In this pilot program, the team will conduct RVSRAs in central neighborhoods of the city such as Armeneasca and Universitate and in outer neighborhoods with taller socialist buildings like Colentina and Lacul Tei. These neighborhoods are located near the intersections of sector 1, sector 2, and sector 3 (see Figure 3.2).

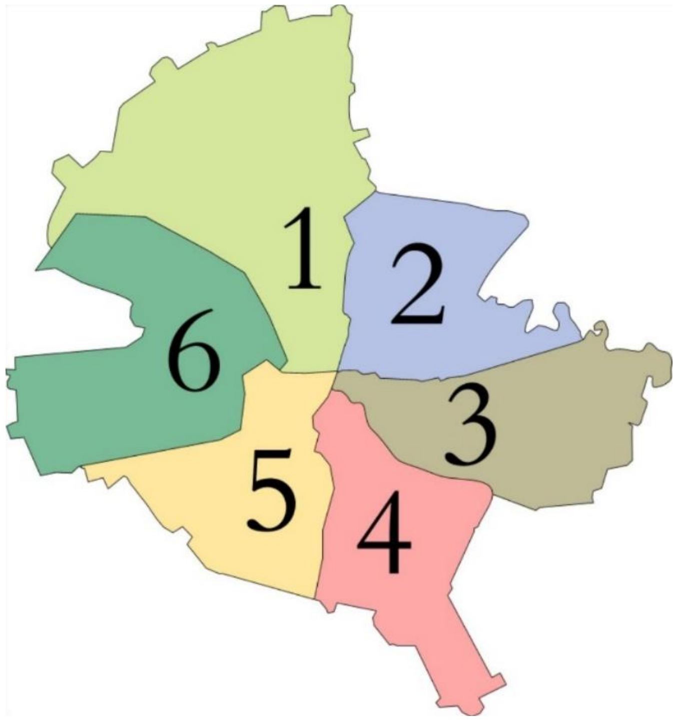

Figure 3.2: Bucharest sectors map (Bucharest Districts Map, n.d.).

Re:Rise chose the neighborhoods because they have existing SRA data on buildings within the neighborhoods. The team plans to use this data in a comparative analysis with RVSRA, which the next section of this chapter will describe.

During the assessment process, the four-person team will split into two teams. By splitting into pairs, the team can assess more buildings than if the whole team assessed each building together, while still allowing each pair to compare results from the same building with each other. Each member will stand on the sidewalk with a clipboard, pencil, and complete a RVSRA form. Elements of the form include street address, visible cracks, and general shape and type of the structure. Although Re:Rise has not yet provided the form that the team will use, a representative remarked that it will be similar to the form that FEMA uses (see Appendix F) for a rapid visual screening for potential seismic hazards.

The form by FEMA is divided into several main sections including building identification information, photograph of the building, sketch of the building, building characteristics, scores and scoring modifiers, comments, and actions required. The building identification information section includes prompts for the assessor to record a building's address, name, and geographic coordinates. The photograph section provides visual identification for the building. The sketch of the building is typically a plan sketch – the layout of the building from a topographic point of view. The purpose of the sketch is to emphasize significant features of the building. The building characteristics section includes prompts for the building's number of stories, year built, soil type, and irregularities. The comments section gives the assessor the opportunity to record any unusual circumstances, uncertainties, or any other significant details not captured in the form elsewhere. The form formulates a basic score using the building type, such as wood frame, steel frame, or reinforced masonry building. Then the form provides score modifiers for building irregularities, seismic code compliance, and soil type for the assessor to apply in achieving the final score. In the actions required section, the form outlines options for additional evaluation based on the final score. FEMA's *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* provides a comprehensive description of the form and their RVSRA process (Applied Technology Council, 2016). The Re:Rise provided form will capture similar information and use a scoring a system like the FEMA form.

One potential limitation of this approach is the citizens of Bucharest may be uncomfortable with a group of people surveying their building. To address this, a Re:Rise representative will always accompany each pair during the assessment to address any questions and concerns from citizens. Re:Rise has worked extensively with communities in Bucharest to reduce seismic vulnerability through other projects. The public awareness of Re:Rise increases credibility to any activities related to the RVSRA. Additionally, Re:Rise will give the team construction vests and a form of identification to enforce the team's credibility.

3.3 Determine Relevance of Rapid Visual Seismic Risk Assessment Methods

To determine the relevance of using RVSRAs in Bucharest, the team will perform a comparative analysis using the team's results to existing SRA data, provided by Re:Rise. The team will then analyze the benefits and drawbacks of using RVSRAs compared to SRAs, in categories such as accuracy, time taken, and cost of each assessment. Other categories may be considered because of the findings from objective 1. Once the team has compared the assessments, with guidance from Re:Rise, the team will weigh the specific categories accordingly to formulate conclusions that determine the usefulness of RVSRAs in Bucharest.

The team will provide recommendations and a report on the findings to Re:Rise, which they can use to further refine their methods of conducting RVSRAs. Additionally, with Re:Rise's permission, the team will incorporate the results of the RVSRAs into Re:Rise's seismic vulnerability map. Engineers can utilize this map to prioritize which buildings they need to assess with more complex SRAs. This map is publicly available and will allow residents to see which buildings are most seismically vulnerable.

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Appendix

Appendix A: Table of Commonly Used Terms and Abbreviations

Term	Abbreviation
Medvedev–Sponheuer–Karnik Scale	MSK
Non-Governmental Organization	NGO
Rapid Visual Seismic Risk Assessment	RVSRA
Seismic Risk Assessment	SRA

Appendix B: Medvedev–Sponheuer–Karnik Scale

I. Not perceptible	Not felt, registered only by seismographs. No effect on objects. No damage to buildings.
II. Hardly perceptible	Felt only by individuals at rest. No effect on objects. No damage to buildings.
III. Weak	Felt indoors by a few. Hanging objects swing slightly. No damage to buildings.
IV. Largely observed	Felt indoors by many and felt outdoors only by very few. A few people are awakened. Moderate vibration. Observers feel a slight trembling or swaying of the building, room, bed, chair, etc. China, glasses, windows, and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. No damage to buildings.
V. Fairly strong	Felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room, or furniture. Hanging objects swing considerably. China and glasses clatter together. Doors and windows swing open or shut. In a few cases, window panes break. Liquids oscillate and may spill from fully filled containers. Animals indoors may become uneasy. Slight damage to a few poorly constructed buildings.
VI. Strong	Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors. Small objects may fall and furniture may be shifted. Dishes and glassware may break. Farm animals may be frightened. Visible damage to masonry structures, cracks in plaster. Isolated cracks on the ground.
VII. Very strong	Most people are frightened and try to run outdoors. Furniture is shifted and may be overturned. Objects fall from shelves. Water splashes from containers. Serious damage to older buildings, masonry chimneys collapse. Small landslides.
VIII. Damaging	Many people find it difficult to stand, even outdoors. Furniture may be overturned. Waves may be seen on very soft ground. Older structures partially collapse or sustain considerable damage. Large cracks and fissures open up rockfalls.
IX. Destructive	General panic. People may be forcibly thrown to the ground. Waves are seen on soft ground. Substandard structures collapse. Substantial damage to well-constructed structures. Underground pipelines ruptured. Ground fracturing, widespread landslides.
X. Devastating	Masonry buildings destroyed, infrastructure crippled. Massive landslides. Water bodies may be overtopped, causing flooding of the surrounding areas and formation of new water bodies.
XI. Catastrophic	Most buildings and structures collapse. Widespread ground disturbances, tsunamis.
XII. Very catastrophic	All surface and underground structures completely destroyed. Landscape generally changed, rivers change paths, tsunamis.

Appendix C: Interview Confidentiality Statement

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: To gain expert insight on seismic risk assessments methods and opinions on rapid visual seismic risk assessment methods. This insight will be used to influence a pilot program to rapid visual seismic risk assessments in Bucharest, Romania.

Procedures to be followed: The interviewer will begin by gaining consent from the respondent to be recorded throughout the interview, explain participant confidentiality, and review the purpose of the study. The team will ask a series of questions to the respondent. The duration of the interview is expected to be 30-45 minutes.

Risks to study participants: None

Benefits to research participants and others: None

Record keeping and confidentiality: The team will ask all respondents if the team can record the interview. If a respondent declines, the team will take notes instead. The interview will gather information on current seismic risk assessment methods and rapid visual seismic risk assessment methods. Only the investigators will have access to the recordings, and the team will transcribe and code them for common themes to complement our research. The team will ask the respondents if they can use their name and affiliation (if any).

Compensation or treatment in the event of injury: There is no expected risk of injury or harm. You do not give up any of your legal rights by signing this statement.

For more information about this research, contact: Project Team Group, Josh DeBare, Nick Miragliotta, and Matt Zoner at gr-seismic-risk-d22@wpi.edu

For more information about the rights of research participants, contact: IRB manager, Ruth McKeogh at 508 831- 6699 or irb@wpi.edu

For information in the case of research-related injury, contact: Human Protection Administrator, Gabriel Johnson at 508-831-4989 or gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits.

The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

If using Zoom:

Team will ask: Can we have your oral consent to interview you?

Study Participant Name:

Name of Person who explained this study

If in person, the team will print the following agreement form and request the respondent to fill out:

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

_____________________________ Date: ____________________

Study Participant Signature

____

Study Participant Name (Please print)

_______________________________________ Date: ____________________

Signature of Person who explained this study

Appendix D: Expert Interview Questions

Before any questions are asked in any interview, the team will read aloud the Interview Confidentiality Statement (see Appendix C) to the respondent and obtain permission (oral for Zoom interview or written for in person interview).

Note: Before conducting an interview with an expert, the team will research the respondent to understand their expertise and thus help prepare with potential follow up questions in C2 and C3.

C1 Questions Regarding Demographics and Introductory Questions

- C1.1 What is your name and pronouns?
- C1.2 What is your job title and what company/organization do you work for?
  - C1.2.1 Can we use your name, title and affiliation in any reports or presentations that are the outcome of this interview?
- C1.3 How would you describe your job to someone who knows nothing about civil engineering or earthquakes?
- C1.4 How does your line of work impact seismic safety and preparedness in your local area or around the world?

C2 Seismic Assessment Methods and General Preparedness

- C2.1 Could you describe your previous work on seismic risk assessments?
- C2.2 How does your work relate to or influence current seismic risk assessment methods?
- C2.3 What are the purposes of seismic risk assessments? In what ways to they help improve earthquake preparedness?

C2.4 What are the socio-economic challenges you have encountered when conducting seismic risk assessments?

C2.5 What are the political challenges you have encountered when conducting seismic risk assessments?

C2.6 Have you experienced working with a governmental organization regarding seismic risk assessments? If so, what was it like?

C2.7 What laws are there surrounding seismic risk assessments in your local area? How have they impacted your ability to do seismic risk assessments?

C2.8 What other elements of seismic risk assessments are important that you have not touched on yet?

C3 RVSRAs

C3.1 What is your experience with rapid visual seismic risk assessments?

C3.2 In what circumstances would a RVSRA be more useful than a traditional SRA and vice versa?

C3.3 How does conducting an RVSRA change for the type of building? For example, would assessing a government building be different from an apartment complex be different than a single unit house?

C3.3.1 How does the accuracy of an RVSRA change depending on the type of building?

C3.4 Are there a different set of regulations that exist regarding rapid visual seismic risk assessments compared to typical seismic risk assessments?

C3.5 What challenges have you experienced with conducting rapid visual seismic risk assessments?

C3.5.1 How did you overcome these challenges?

C3.5.2 What could you have done differently to avoid these challenges in the first place?

Appendix E: Qualitative Analysis Codebook

- Traits of SRAs
  - Financial Cost – the financial cost to conduct an SRA
  - Training – the training needed to conduct an SRA
  - Time – the time it takes to conduct an SRA
  - Access – the building access required to conduct an SRA
- Items recorded during SRAs
  - Building type – the type of building based on characteristics like type of structural support
  - Construction period – the period when a building was constructed
  - Government – the type of government that was in power during the construction of a building
  - Building codes – the building codes and seismic design regulations in place during the construction of a building
  - Stories – number of stories a building has

Appendix F: FEMA Rapid Visual Screening of Buildings for Potential Seismic Hazards

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
HIGH Seismicity

PHOTOGRAPH

Address:
Zip:
Other Identifiers:
Building Name:
Use:
Latitude: **Longitude:**
S_S: S_1:
Screener(s): **Date/Time:**

No. Stories: Above Grade: Below Grade: **Year Built:** ☐ EST
Total Floor Area (sq. ft.): **Code Year:**
Additions: ☐ None ☐ Yes, Year(s) Built:

Occupancy: Assembly Commercial Emer. Services ☐ Historic ☐ Shelter
Industrial Office School ☐ Government
Utility Warehouse Residential, #Units:

Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil DNK *If DNK, assume Type D.*

Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK
Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building
Irregularities: ☐ Vertical (type/severity) ☐ Plan (type)
Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer ☐ Parapets ☐ Appendages ☐ Other:

COMMENTS:

SKETCH

☐ Additional sketches or comments on separate page

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	Do Not Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score		**3.6**	**3.2**	**2.9**	**2.1**	**2.0**	**2.6**	**2.0**	**1.7**	**1.5**	**2.0**	**1.2**	**1.6**	**1.4**	**1.7**	**1.7**	**1.0**	**1.5**
Severe Vertical Irregularity, V_{L1}		-1.2	-1.2	-1.2	-1.0	-1.0	-1.1	-1.0	-0.8	-0.9	-1.0	-0.7	-1.0	-0.9	-0.9	-0.9	-0.7	NA
Moderate Vertical Irregularity, V_{L1}		-0.7	-0.7	-0.7	-0.6	-0.6	-0.7	-0.6	-0.5	-0.5	-0.6	-0.4	-0.6	-0.5	-0.5	-0.5	-0.4	NA
Plan Irregularity, P_{L1}		-1.1	-1.0	-1.0	-0.8	-0.7	-0.9	-0.7	-0.6	-0.6	-0.8	-0.5	-0.7	-0.6	-0.7	-0.7	-0.4	NA
Pre-Code		-1.1	-1.0	-0.9	-0.6	-0.6	-0.8	-0.6	-0.2	-0.4	-0.7	-0.1	-0.5	-0.3	-0.5	-0.5	0.0	-0.1
Post-Benchmark		1.6	1.9	2.2	1.4	1.4	1.1	1.9	NA	1.9	2.1	NA	2.0	2.4	2.1	2.1	NA	1.2
Soil Type A or B		0.1	0.3	0.5	0.4	0.6	0.1	0.6	0.5	0.4	0.5	0.3	0.6	0.4	0.5	0.5	0.3	0.3
Soil Type E (1-3 stories)		0.2	0.2	0.1	-0.2	-0.4	0.2	-0.1	-0.4	0.0	0.0	-0.2	-0.3	-0.1	-0.1	-0.1	-0.2	-0.4
Soil Type E (> 3 stories)		-0.3	-0.6	-0.9	-0.6	-0.6	NA	-0.6	-0.4	-0.5	-0.7	-0.3	NA	-0.4	-0.5	-0.6	-0.2	NA
Minimum Score, S_{MIN}		*1.1*	*0.9*	*0.7*	*0.5*	*0.5*	*0.6*	*0.5*	*0.5*	*0.3*	*0.3*	*0.3*	*0.2*	*0.2*	*0.3*	*0.3*	*0.2*	*1.0*

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$:

EXTENT OF REVIEW
Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source:
Geologic Hazards Source:
Contact Person:

LEVEL 2 SCREENING PERFORMED?
☐ Yes, Final Level 2 Score, S_{L2} ☐ No
Nonstructural hazards? ☐ Yes ☐ No

OTHER HAZARDS
Are There Hazards That Trigger A Detailed Structural Evaluation?
☐ Pounding potential (unless S_{L2} > cut-off, if known)
☐ Falling hazards from taller adjacent building
☐ Geologic hazards or Soil Type F
☐ Significant damage/deterioration to the structural system

ACTION REQUIRED
Detailed Structural Evaluation Required?
☐ Yes, unknown FEMA building type or other building
☐ Yes, score less than cut-off
☐ Yes, other hazards present
☐ No
Detailed Nonstructural Evaluation Recommended? *(check one)*
☐ Yes, nonstructural hazards identified that should be evaluated
☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data OR DNK = Do Not Know