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International Journal of Architectural Heritage
Conservation, Analysis, and Restoration

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/uarc20

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INTERNATIONAL JOURNAL OF ARCHITECTURAL HERITAGE
https://doi.org/10.1080/15583058.2024.2341054

Simplified Vulnerability Assessment of Historical Churches in Banat Seismic Region, Romania

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ABSTRACT
Romania, a mid-eastern European country, has a moderate seismicity and a large stock of historical buildings and churches. One of the most important seismic areas of the country is the Banat area, which ranks as the second most seismic area in Romania, with shallow earthquakes of crustal type. Many Orthodox and Catholic churches can be found in the area, the majority of them having a central nave. The churches are built in masonry, with vaults and wooden frameworks, and they present valuable architectural-artistic details, including paintings made by recognized painters. Various forms of structural damage appeared to the historical churches after past earthquakes, depending on the architectural configuration. This paper illustrates a study made on six historic churches in the Banat region, to investigate seismic vulnerability with simplified methods. The study highlights the most vulnerable points of the historic religious structures and the importance of investigating in a quick and simplified way the seismic behavior of such important buildings for the local community. Moreover, the main novelty of the paper is the highlighting of the importance of the sustainability aspect in the process of heritage preservation, as simplified assessment procedures are essential for more resilient risk reduction policies.

ARTICLE HISTORY
Received 27 February 2024
Accepted 2 April 2024

KEYWORDS
cultural value; masonry churches; seismic behaviour; sustainability; vulnerability assessment

1. Introduction

1.1. Opportunity of the study

One of the most complex architectural programs is represented by the churches, which are very important for the local communities, due to their religious and cultural value. Made of wood, stone, or masonry, they are well preserved even nowadays, despite being built before the existence of any design codes, or their ages, as they are one of the most representative architectural objects.

As the Orthodox religion is very present in the life of the people in Romania, the religious one is still one of the most representative architectural edifices. On the territory of the country, there are thousands of Orthodox churches and also several Catholic and other religious ones. Most of them are still used, and they continue to represent a point of interest, especially for rural communities' life.

Assessing the seismic vulnerability of such complex architectural and structural churches represents a difficult task, especially due to their architectural-artistic, symbolic, and cultural value. Depending on the structural configuration of the churches and the earthquake type, expected damages can be very different, as shown in various studies made in Romania (Mosoarca and Gioncu 2013), southern Italy (Formisano et al. 2018), central Italy (Clementi et al. 2020), and specifically Banat region (Fofiu et al. 2021). Some of the studies are supported by user-reported data and the modern Internet of Things (Uva et al. 2019), while others are based on visual inspection, numerical analysis, and a macro-element approach (Sangiorgio, Uva, and Adam 2021).

One of the most common failure types for churches is the failure rigid blocks mechanism, as previous studies made on Orthodox and Catholic edifices were made (Mosoarca and Gioncu 2013). Other recent studies based on the comparison between numerical analysis and real damages observed after past earthquakes maintain the previous idea (Lo Monaco et al. 2022).

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Some novel research works indicate a possibility of using archetype buildings for an interview-based approach with a mechanical method that can be used later on a territorial scale (Ruggieri et al. 2023). Another important challenge is the elevated exposure of the churches due to specific structural configurations and deficiencies, which increases the seismic risk. Also, any damage to cultural and artistic artwork that is very common to those kinds of buildings would represent important cultural and economic losses (Ruggieri et al. 2020).

Moreover, the state-of-the-art research indicated a lack of correlation between sustainability aspects and vulnerability assessment. Following simplified procedures to evaluate the vulnerability of a building, church, or entire area represents a very useful tool for a more sustainable approach, but a new, innovative procedure that will consider also the sustainability level of the actual existing interventions would be important. Considering the sustainability aspects of the assessment procedures would represent an opportunity for future more resilient risk-reduction policies, with a better impact on the built environment.

1.2. Seismicity of Banat region

The six churches that are investigated are located in the second most important seismic zone of the country, Banat region.

The seismicity of the area is highlighted in Figure 1b (Lo Monaco et al. 2022), by overlapping the map of the European seismic hazard (Woessner et al. 2015) with the map of the peak ground acceleration based on the Romanian legislation (Ministry of Regional Development Public Administration and European Funds, 2013).

The area has a moderate seismicity, characterized by shallow earthquakes of crustal type. The vertical forces are the most powerful, and the focal depths are small (Mosoarca et al. 2020). In the region, there was recorded a maximum of 5.6 magnitude. The peak ground acceleration can vary from 0.15 g to 0.20 g in various locations of the Banat region.

Following Equation 1 (Onescu, Onescu, and Mosoarca 2021), the most probable macroseismic intensity was determined for the investigated churches, which is VIII EMS-98 in the areas with 0.15 g PGA and IX EMS-98 in the regions with PGA = 0.20 G.

$$ln(PGA) = 0.24xI_{EMS-98} - 3.9 \quad (1)$$

2. Case study churches

The research focuses on representative Orthodox masonry churches from Banat area. There were selected six churches, from which five are located in Timis county, and one in Caras-Severin county, as illustrated in Figure 2.

2.1. Architectural configuration and structural system

The six churches that were selected for the research study are considered representative of the architectural style of religious buildings in the Banat area, with a unique nave and a rectangular plan, very similar regarding their architecture, built in the XVIII-XIX Century.

Some representative elements of the architecture of the Orthodox churches in the area are present in all investigated churches, such as the pronaos (also called narthex), the naos (also called the central nave), the iconostasis

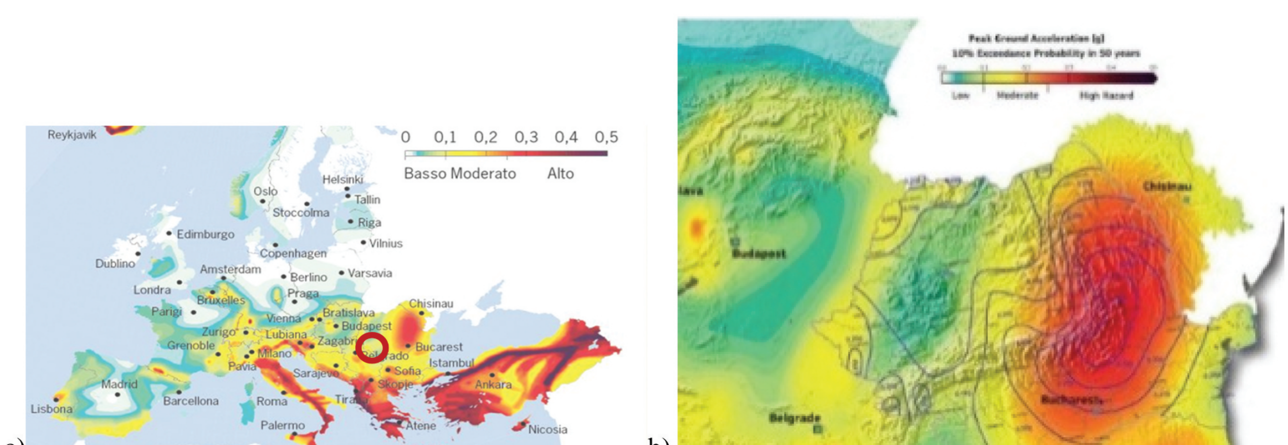


Figure 1. a) Localization of Banat seismic area on the European seismic hazard map (Woessner et al. 2015); b) overlayed map for Romania (Lo Monaco et al. 2022).

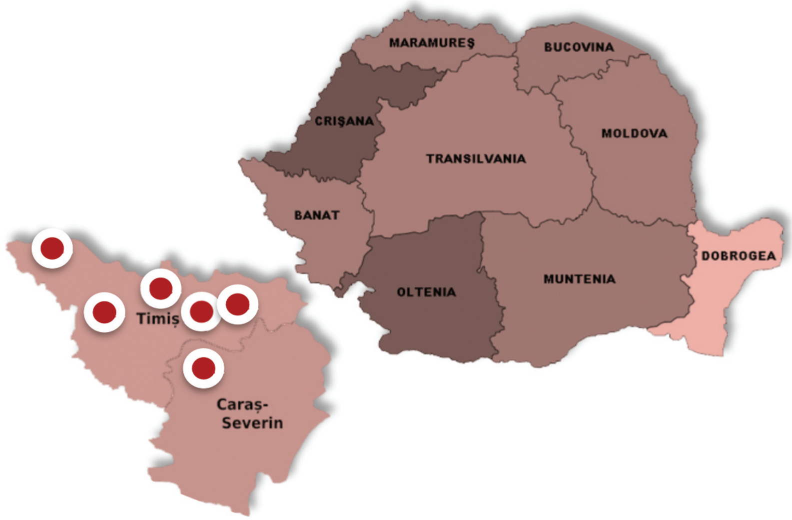


Figure 2. Localization of the investigated churches.

(which is the wooden wall that separates the naos from the altar), the altar (sanctuary) and the bell tower, which is always located in the main façade, centrally, leading to a typical architectural configuration, as illustrated in Figure 3 (Lo Monaco et al. 2022).

The structure of the investigated churches is based on massive perimetral masonry walls, made from masonry clay brick and lime. Masonry is also used for the foundation of buildings, in some cases stone, leading to continuous foundation walls under the masonry walls. One representative element is the bell tower, which is always one, located centrally on the main façade, made also in masonry, with a wooden spire at the top. Usually, there is a mezzanine in the pronaos area. Masonry arches and vaults can be found, but in some cases, they are not structural, but only built for architectural spatial reasons, such as in the cases of the churches in Bencecu de Jos, Chizatau, and Cenad. The altar shape is usually hexagonal or circular, while the roof is made in a wooden framework, with a pitched shape. The exact structural configuration of each church can be seen in Tables 1 and 2 (Lo Monaco et al. 2022).

As a conclusion of the typological structure and architecture of all investigated churches, the bearing walls, and the bell tower are made in brick or mixed stone-brick masonry, the vaults are made in brick masonry or plasterboard-wooden plank, the spire and mezzanine are made in wood, and the pitched roofs are also made in wooden frameworks. All six churches are configured with a single central nave, one central bell tower incorporated in the main façade, and a rounded sanctuary. The differences are related to the dimensions of the six churches, the highest of them being the one in Bocsa, with a bell tower height of 35.33 meters. Some constructive details can also be seen in Figure 4.

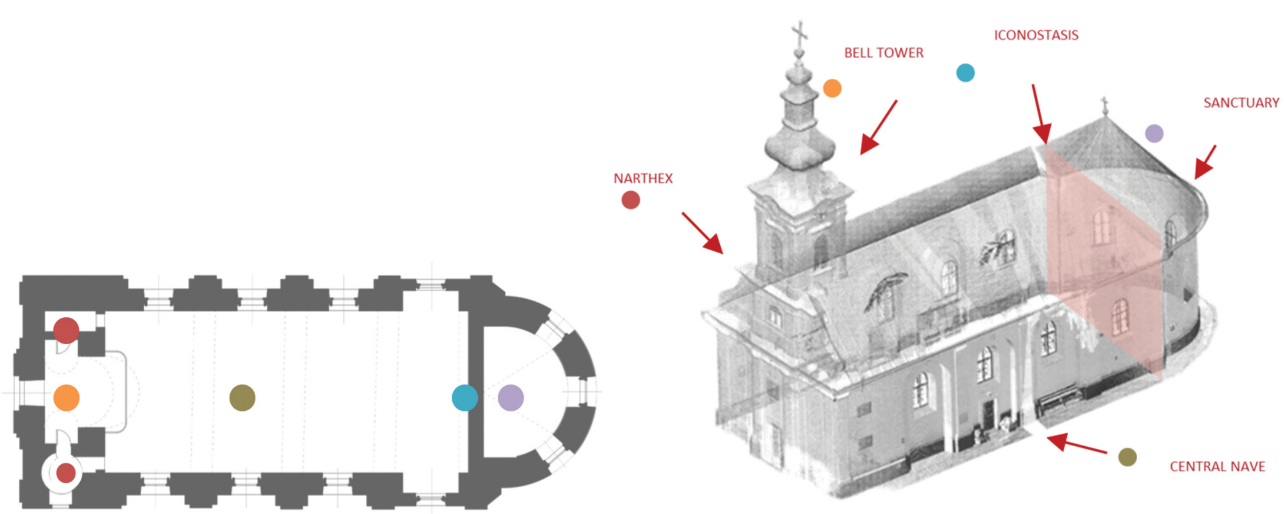


Figure 3. Architectural typical configuration of the investigated churches (Lo Monaco et al. 2022).

Table 1. Structural configuration of the investigated churches (Lo Monaco et al. 2022.).

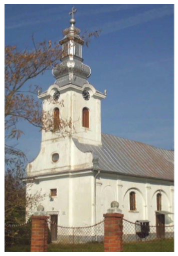
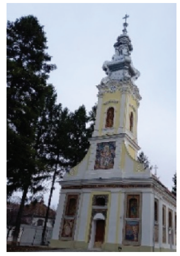
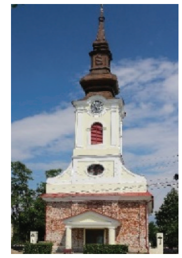
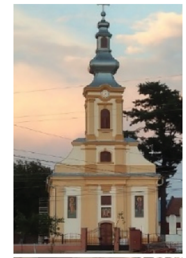
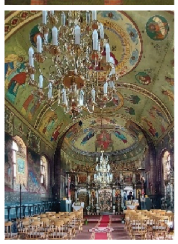
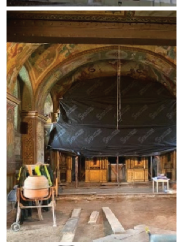
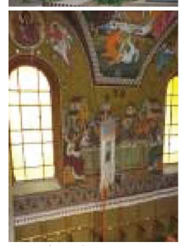
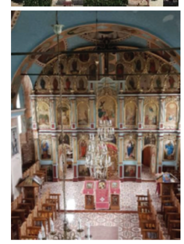
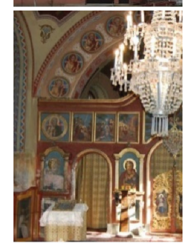
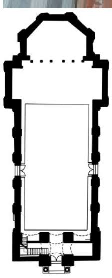
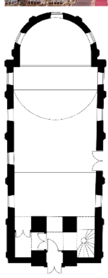
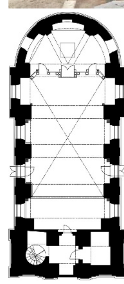
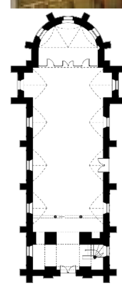
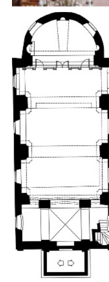
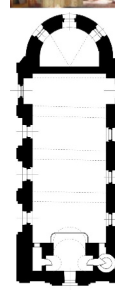
1 Pogorârea Sfântului Duh (Holy Spirit Descent)	2 Nasterea Maicii Domnului (God's Mother Nativity)	3 Sfintul Nicolae (Saint Nicholas)	4 Sfantul Nicolae (Saint Nicholas)	5 Sfântul Gheorghe (Saint George)	6 Învierea Domnului (Jesus Resurrection)
Municipality of Cenad	Municipality of Chizatau	Municipality of Bocsa	Municipality of Bencecu de Jos	Municipality of Beregsău Mare	Municipality of Belint
					
					
					

Table 2. Synthesis of the decay observed in the investigated churches.

1	**Construction period and location**: 1888, flat rural area of Cenad **Bearing walls material and thickness**: brick masonry, 70–75 cm **Vaults**: wooden barrel vault with lunettes (false-vault) **Bell tower height**: 26.15 m **Damages recorded**: cracks on walls, damaged plaster and paintings	4	**Construction period and location**: 1899, hilly area of Bencecu de Jos **Bearing walls material and thickness**: brick masonry, 55–75 cm **Vaults**: plasterboard and wooden plank barrel vault with lunettes **Bell tower height**: 23.27 m **Damages recorded**: cracks on walls, damaged plaster and paintings
2	**Construction period and location**: 1827, flat rural area of Chizătău **Bearing walls material and thickness**: brick masonry, 57–97 cm **Vaults**: wooden barrel vaults and arches **Bell tower height**: 23.21 m **Damages recorded**: cracks on walls, damaged plaster and paintings, cracks between tower walls and longitudinal walls	5	**Construction period and location**: 1793–1810, flat rural area of Beregsău Mare **Bearing walls material and thickness**: brick masonry, 35–75 cm **Vaults**: brick masonry barrel vaults and arches **Bell tower height**: 27.96 m **Damages recorded**: cracks on walls, damaged plaster and paintings
3	**Construction period and location**: 1795–1911, city of Bocsa **Bearing walls material and thickness**: stone-brick masonry, 100–160 cm **Vaults**: brick masonry barrel vaults and arches **Bell tower height**: 35.33 m **Damages recorded**: damaged plaster and paintings	6	**Construction period and location**: 1797, flat rural area of Belinț **Bearing walls material and thickness**: brick masonry, 70–170 cm **Vaults**: brick masonry barrel vaults and arches **Bell tower height**: 25.80 m **Damages recorded before interventions**: vertical cracks in the apse area

2.2. Level of decay

Some common decay elements were found for all investigated religious edifices, such as the vertical cracks on the exterior facades, in proximity to the openings. Other cracks between the longitudinal wall and the bell tower were noticed during on-site inspection, as well as cracks in the masonry vaults and arches, as presented in Figure 5. The main cause of the observed decay is the different settlements. The decay is also non-structural, being observed on the plaster and paintings, with superficial plaster cracks. The synthesis of the observed damages and details is presented in Table 2.

As a conclusion of the typological structure and architecture of all investigated churches, the bearing walls, and the bell tower are made in brick or mixed stone-brick masonry, the vaults are made in brick masonry or plasterboard-wooden plank, the spire and mezzanine are made in wood, and the pitched roofs are also made in wooden frameworks.

Figure 4. Constructive details of the Belint church.

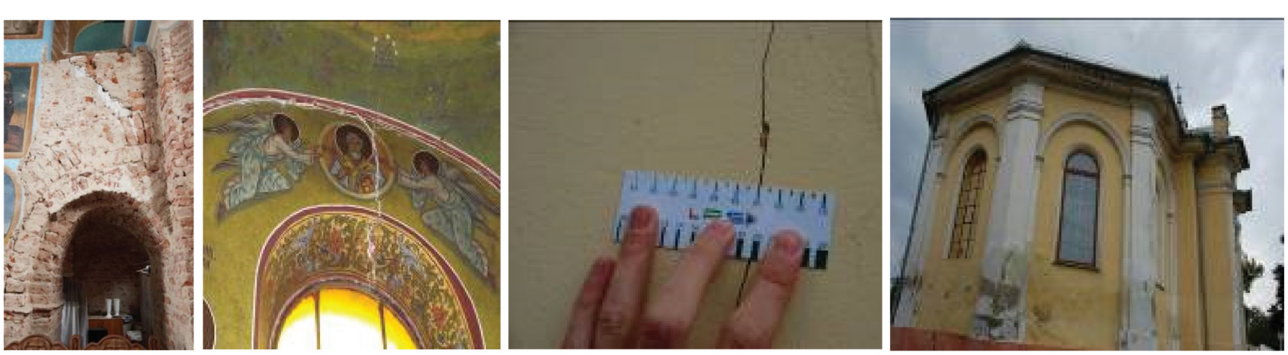


Figure 5. Damage and cracks observed in the investigated churches.

Table 3. Vulnerability forms for empirical vulnerability assessment.

%	Criteria	No.	Element	Class A	Class B	Class C	Class D	Weight
70%	STRUCTURAL	1	Vertical structure organization	0	5	20	45	1.00
		2	Vertical structure nature	0	5	25	45	0.25
		3	Type of foundation and location/soil	0	5	25	45	0.75
		4	Distribution of structural elements in plan	0	5	25	45	1.50
		5	Regularity in plan	0	5	25	45	0.50
		6	Regularity in elevation	0	5	25	45	1.00
		7	Floor type	0	5	15	45	0.75
		8	Roofing	0	15	25	45	0.75
		9	Other details	0	0	25	45	0.25
		10	Conservation state	0	5	25	45	1.00
15%	ARCHITECTURAL ARTISTIC	11	Representative architectural style for the area	0	10	15	25	1.50
		12	Age, importance of the build époque	0	10	15	25	1.20
		13	Original woodwork/joinery	0	10	15	25	1.00
		14	Original stucco, brick, floors or ceilings	0	10	15	25	1.00
		15	Original statues or bass-reliefs	0	10	15	25	1.00
		16	Original gable/fronton	0	10	15	25	1.00
		17	Original balconies and railings	0	10	15	25	1.00
		18	Original mosaics or stonework	0	10	15	25	1.00
		19	Original paintings or frescoes	0	10	15	25	1.00
		20	Degradation state of artistic assets	−5	10	15	25	1.00
		21	Authenticity/originality (global, elements)	0	10	15	25	1.00
		22	Official monument (national, regional, local, protected area) status	0	10	15	25	1.50
		23	Particular construction techniques/materials	0	10	15	25	0.50
		24	Conservation state of original materials	−5	10	15	25	0.50
		25	Representative historical events	0	10	15	25	0.50
		26	Archaeological site	0	10	15	25	1.50
		27	Representative/original wooden framework	0	10	15	25	1.00
		28	Past restoration work	−5	10	15	25	1.00
10%	URBANISTIC	29	Importance in contouring the street profile	−5	10	15	25	1.50
		30	Importance in contouring the urban silhouette	−5	10	15	25	1.50
		31	Annexes, relation with the urban pattern	0	10	15	25	1.00
		32	Location (central area, touristic area)	0	10	15	25	1.50
		33	Representative/particular shape of the roof	0	10	15	25	1.00
5%	SOCIAL ECONOMIC	34	Public/social functions	0	10	15	25	1.50
		35	Importance for the local community memory	−5	10	15	25	1.00
		36	Economic value	0	10	15	25	1.50
		37	Cultural functions	0	10	15	25	1.50
					$I_{V\ CULT}$			

3. Simplified vulnerability assessment

3.1. Empiric vulnerability assessment with cultural value

One of the methodologies that were applied for assessing the vulnerability of the six investigated Orthodox churches in the Banat area is the well-known empiric European procedure, developed by Benedetti and Petrini (Benedetti and Petrini 1984). In addition to that method, the methodology was developed by Onescu (Apostol 2020) to consider not only the structural parameters but also the architectural-artistic, urbanistic, and socio-economic ones. The base of the assessment consists of a visual inspection and a correlation with a vulnerability form that contains 37 parameters, from which only the first 10 refer to the structure of the investigated buildings, being exactly the same as in the methodology of Benedeti and Petrini. The other ones refer to architectural-artistic, urbanistic, and socio-economic aspects and represent the original contribution of the authors Onescu and Mosoarca, with the main aim of considering the cultural value of the assessed buildings. After the fulfilment of the vulnerability form, there is obtained a vulnerability index as the sum of each individual score of the assessed vulnerability class multiplied by an associated weight, as in Equations 2 and 3 (Onescu, Onescu, and Mosoarca 2021). The final vulnerability form is presented in Table 3.

$$I_{VSTRUCT} = \sum_{i=1}^{10} s_i \times w_i \tag{2}$$

$$I_{VCULT} = 0.70 \times \sum_{i=1}^{10} s_i \times w_i + 0.15 \times \sum_{i=11}^{28} s_i \times w_i + 0.10 \times \sum_{i=29}^{33} s_i \times w_i + 0.05 \times \sum_{i=34}^{37} s_i \times w_i \tag{3}$$

Following Equation 4, there is obtained the mean damage. Following the vulnerability curve by means of a hyperbolic function developed by Sandi and Floricel (Sandi and Floricel 1994), for an expected macroseismic intensity for each church (Onescu,

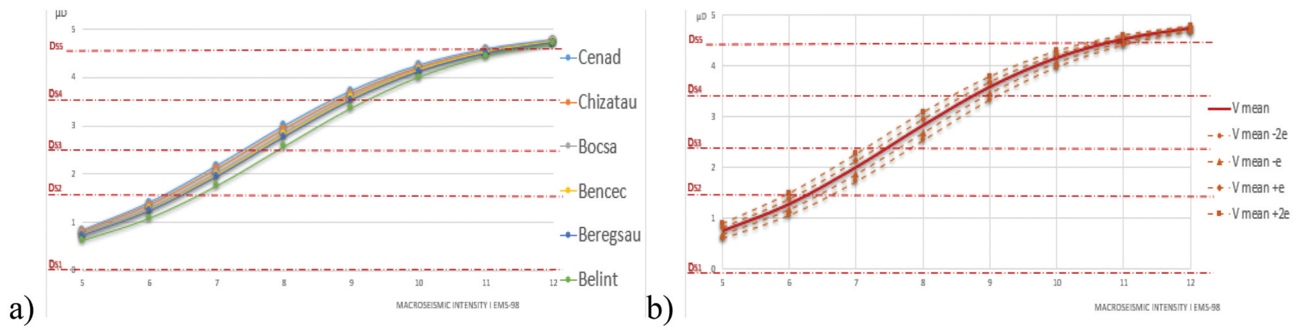


Figure 6. Only structural assessment: a) Individual vulnerability curves; b) mean vulnerability curve for all six churches.

Onescu, and Mosoarca 2021), there can be determined the most expected damage state.

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25 \times V_{CULT} - 13.1}{\Phi}\right)\right] \quad (4)$$

Where V_{CULT} represents the vulnerability index which considers also the cultural value, in the range from 0 to 1, I is the macroseismic intensity of the area, and Φ represents a factor that influences the slope of the curve, which is considered to be 2.3 for residential buildings, and 3 for churches (Zizi et al. 2021).

Furthermore, the vulnerability curve function was calibrated specifically for masonry churches by Prof. Lagomarsino and Podesta (Lagomarsino and Podesta 2004), following the damages observed after the 1997 earthquake from Umbria and Marche areas. After performing an extended analysis of over 2000 churches, their research led to the following mean damage formula (Equation 5):

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 3.4375 \times V_{CULT} - 8.9125}{\Phi}\right)\right] \quad (5)$$

Where Φ is considered again with the value 3 for masonry churches [16].

3.1.1. Vulnerability assessment results without considering the cultural value

By applying only, the original methodology of Benedetti and Petrini (Benedetti and Petrini 1984), and the adapted mean damage assessment equation for masonry churches (Mosoarca et al. 2020), there was obtained the seismic vulnerability assessment of the six churches, from a structural point of view. The vulnerability curve for each church, together with the mean vulnerability curve of all six churches without the cultural value considered is presented in Figure 6.

A medium seismic vulnerability for all the six investigated churches is indicated by the results, in the range of damage states D2-D4 for the probable macroseismic intensities VIII and IX EMS-98. The most expected damage state for the churches that are located in areas with PGA = 0.15 g and expected macroseismic intensity VIII EMS-98 is D2 damage state, while the churches that are located in areas with PGA = 0.20 g and expected macroseismic intensity IX EMS-98 are in D3-D4 damage state.

The results indicated a probability of having moderate-to-severe damage to the elements that are non-structural, and in some cases slight to moderate damage to the structural elements. These results are in accordance with the real damages observed during on-site investigations.

3.1.2. Vulnerability assessment results with the cultural value considered

By applying the original methodology of the authors Onescu and Mosoarca, which considers also architectural-artistic, urbanistic, and socio-economic parameters (Apostol 2020), there was determined the seismic vulnerability influenced by cultural value. The vulnerability curve for each church, together with the mean vulnerability curve of all six churches with the cultural value considered is presented in Figure 7.

As previously determined, the results in this case also highlight a medium seismic vulnerability for all six churches, indicating the most probable damage states D2-D4 for the expected macroseismic intensities VIII and IX EMS-98.

A comparison between the results obtained when the cultural value of the churches was considered and when it did not indicate only a slight change of vulnerability. The tendency when the cultural value is considered is to decrease the vulnerability by 1–2%. The difference is minor, and that happens because the investigated churches had already a very similar vulnerability, as

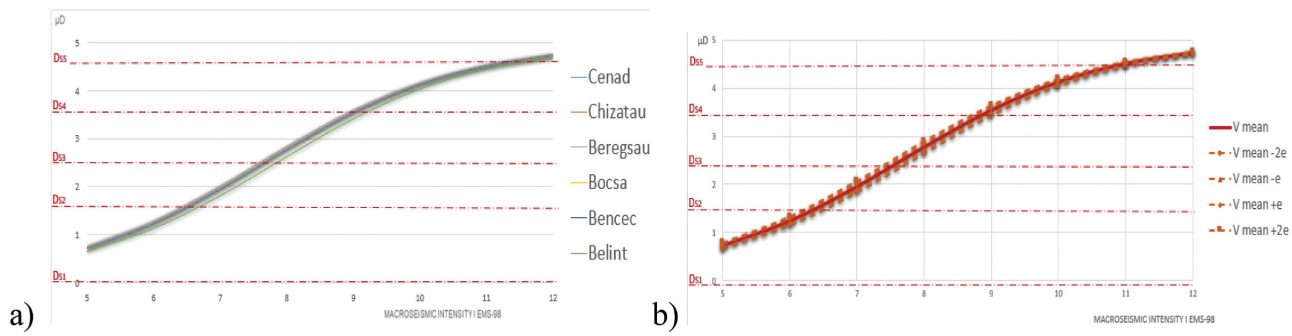


Figure 7. With cultural value: a) Individual vulnerability curves; b) mean vulnerability curve for all six churches.

they were very similar to each other. Moreover, the consideration of cultural value tends to bring all the vulnerability indexes in the same range, as all the investigated buildings are very similar in terms of architectural-artistic, urbanistic, and socio-economic values. So, even if the structural vulnerability of the six churches is a bit different, the cultural vulnerability is much more similar, as presented in Figure 8.

3.2. *Vulnerability assessment based on Italian methodology*

The Italian Directive 47 of 2011 (Directive of the Prime Minister G.U. N. 47 2011) indicates that there can be considered 3 different levels of seismic risk assessment (Levels of Valuation LV1, LV2, and LV3) when assessing the vulnerability of a building or an area, for cultural heritage, depending on the complexity of the investigation. The most common procedure focuses on the LV1-Level assessment, and follows a qualitative analysis based on visual on-site investigation and survey, defining the seismic capacity of the structure expressed in terms of PGA, following Equations 5and 6 (Lo Monaco et al. 2022).

$$i_v = \frac{1}{6} \cdot \frac{\sum_{k=1}^{28} \rho_k \cdot \left(v_{k_i} - v_{kp}\right)}{\sum_{k=1}^{28} \rho_k} + \frac{1}{2} \tag{6}$$

$$a_{LSLS} S = 0.025 \cdot 1.8^{5.1 - 3.44 i_v} [g] \tag{7}$$

Where ρ_k is the weight is considered for each possible collapse mechanism (0 if not present, or ranging 0,5–1), vki is the score assigned for the k-th mechanism which refers to the evaluated vulnerability, and vkp is the score assigned for the k-th mechanism which refers to the seismic-resistant advice. S is a coefficient depending on subsoil and topographic categories.

Following this multi-level approach, in Diaz Fuentes (Andrea and Fuentes 2016) and in D'Amato et al. (D'Amato, Laterza, and Diaz Fuentes 2020), there can be found an innovative proposal that highlights a simplified level of evaluation, the LV0, which is appropriate for territorial scale evaluation. The LV0 represents a combination of Hazard H and vulnerability V, following Equations 7 (Lo Monaco et al. 2022) and provides a Risk score R.

$$R = [H + 1] \times V, H = \sum_{k=1}^{7} h_{k,i}, V = \sum_{k=1}^{13} \rho_{k,i} v_{k,i} \tag{8}$$

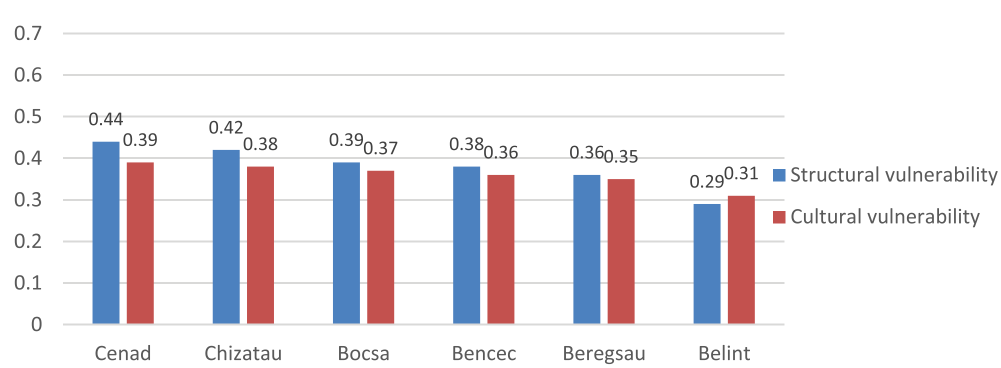


Figure 8. The results ordered in a top of the most vulnerable churches according to empiric methodology.

3.2.1. Results of the LV0 and LV1 methodology

Following the LV1 Italian methodology, the results in terms of global vulnerability index based on the acceleration expected for each investigated religious edifice are presented in Table 4. The calculation of the acceleration factor is made by dividing the obtained acceleration by the ground acceleration that is characteristic to a specific area for the considered limit state.

In Figure 9, there are presented the results obtained following both LV0 and LV1 analysis. There can be noticed a good correlation between those two different valuation levels, as both methodologies indicate the church of Cenad as the most vulnerable, while the least vulnerable seems to be the church in Belint in both cases. The obtained horizontal acceleration at LSLS is $a_{Og,LSLS} = 0.080\ g \div 0.115\ g$, and the obtained vertical acceleration at LSLS is $a_{Vg,LSLS} = 0.081\ g \div 0.116\ g$. The expected ag on rock soil (TR = 225 years) is 0.15 g for the churches in Chizatau, Belint, and Bocsa and 0.20 g for the churches in Cenad, Bencecu de Jos and Beregsau Mare.

3.3. Comparison between Romanian and Italian methodologies results

The results obtained after applying various Romanian and Italian vulnerability assessment procedures to the six investigated churches in the Banat area indicated in all cases a medium seismic vulnerability, highlighting a possibility of moderate damages to the structural elements and extended damages to non-structural ones.

The Romanian procedure tends to underestimate the expected damage in comparison with the Italian procedure. These results are expected, as the Romanian methodology is more simplified than the Italian one and considered fewer possible failure mechanism regarding the structural vulnerability of the investigated church. Despite this slight difference, the expected mean damage following the Romanian methodology also indicates a medium vulnerability, which is consistent with the damage state of the existing investigated masonry churches that was observed after on-site investigation. A comparison between the vulnerability indexes is presented in Figure 10.

4. Sustainability and resilience of empirical assessment

The seismic vulnerability assessment of historical buildings and churches represents a useful tool in the process of heritage preservation. While technical reports and numerical analysis are more accurate, they need numerous financial and human resources, leading to a very increased analysis time. That is why, simplified assessment procedures represent a more sustainable procedure for a resilient risk reduction strategy, as they allow local authorities to quickly evaluate a very large number of

Table 4. Global vulnerability index for the investigated churches according to LV1 analysis.

Church	i_v (global vulnerability index)	F_C (confidence factor)	a_g [g] expected	$a_{Og,LSLS}$ [g] - horizontal ground acceleration/F_c in Life-Safety Limit State	$f_{aO,SLV}$ - horizontal acceleration factor at Life-Safety Limit State	$a_{Vg,LSLS}S$ [g] - vertical ground acceleration/F_c in Life-Safety Limit State	$f_{aV,SLV}$ - vertical acceleration factor at Life-Safety Limit State
Holy Spirit Descent Church (CENAD)	0.587	1.35	0.2	0.081	0.405	0.083	0.414
God's Mother Nativity Church (CHIZATAU)	0.566		0.15	0.080	0.534	0.081	0.542
Saint Nicholas Church (BOCSA)	0.460		0.15	0.099	0.661	0.101	0.672
Saint Nicholas Church (BENCECU DE JOS)	0.450		0.2	0.107	0.534	0.109	0.545
Saint George Church (BERGSAU MARE)	0.428		0.2	0.112	0.558	0.114	0.570
Jesus Resurrection Church (BELINT)	0.389		0.15	0.115	0.763	0.116	0.775

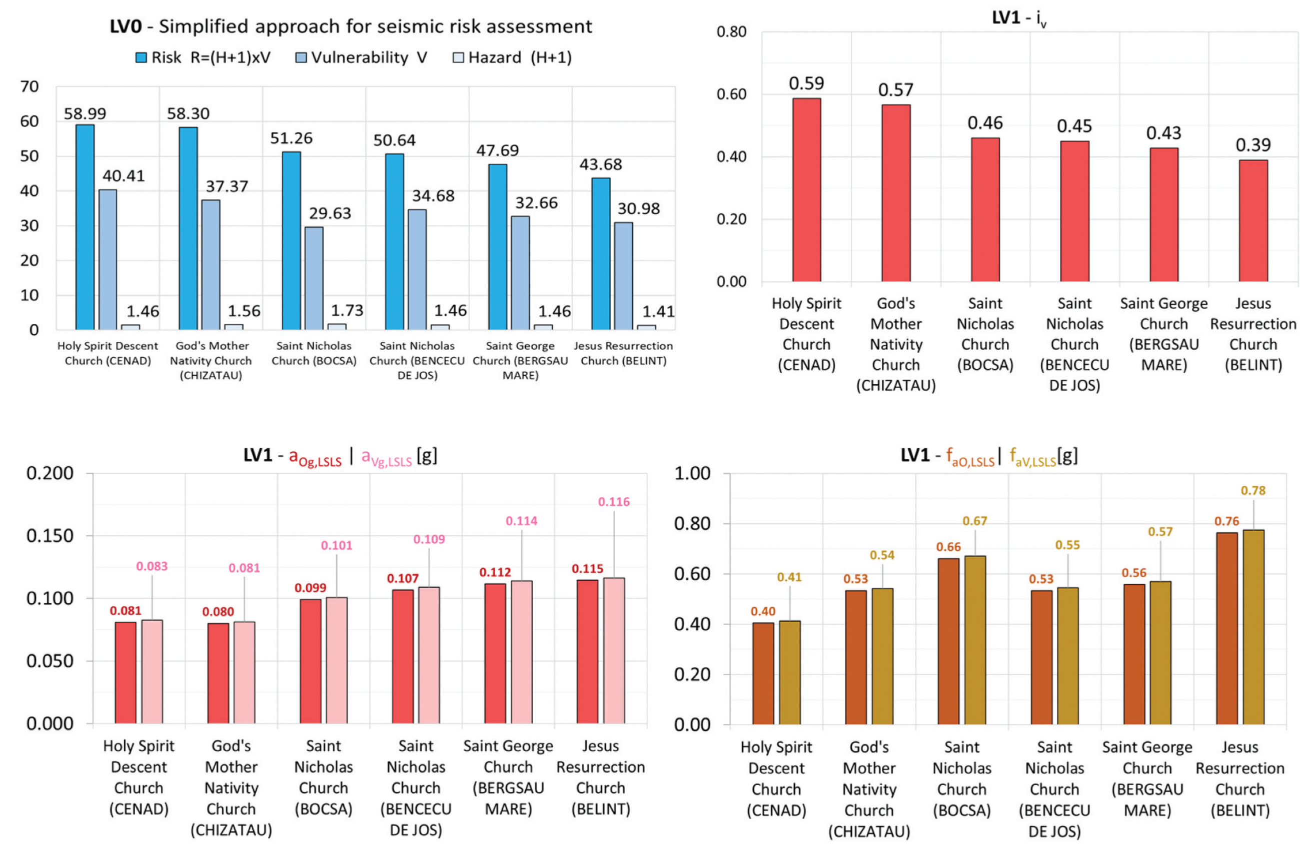


Figure 9. The results following LV0 and LV1 methodology.

buildings and churches, with minimum financial and human resources. This simplified assessment offers a global view of the state of the heritage buildings, indicating the ones that are the most vulnerable, so extended analysis could be performed only on those. Nowadays, there is little information about the sustainability of the historical areas and buildings, some of them regarding the life cycle assessment, but the research topic is still developing (Loli and Bertolin 2021).

Moreover, sustainability is to be expected also in the strengthening process of the architectural heritage buildings and churches, as the built environment is accountable for more or less of 40% of all greenhouse gas emissions. The use of resilient strengthening methods and compatible materials represents one of the modern tasks in the conservation and restoration process, together with the task of improving the quality of the living and using conditions (Mosoarca, Onescu, and Mosoarca 2023). Considering the fact that the primary reason for which heritage buildings are forsaken is tthe lack of financial funds for investigation and restoration, there is highlighted the need for a multidisciplinary simplified procedure that will provide a viable scheme for the preservation of the architectural heritage (Mosoarca and Onescu 2023).

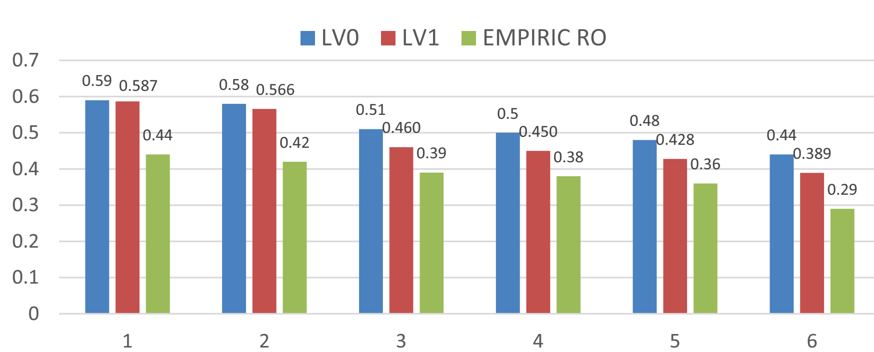


Figure 10. Comparison between the different methodologies results.

The sustainability aspect is to be considered not only in the design process of new buildings but also in the restoration process of the old ones. The continuously growing population, the increased building and construction activity, the climate change, and other factors have led to an increase in the vulnerability level of existing buildings, which are already vulnerable to the permanently changing hazard scenarios. To achieve a sustainable decision-making framework, there have to be considered multi-criterial aspects, such as performance-assessment procedures, sustainability assessment, and resilience-assessment, as shown in Figure 11 (Anwar 2022).

The surveys that were conducted after past earthquakes, especially in Italy, showed considerable damage to masonry churches, highlighting the necessity of increasing the knowledge level and of improving the existing assessment methodologies for preserving the valuable cultural heritage by means of risk mitigation. The first step in the risk mitigation process is the proper seismic vulnerability assessment of the vulnerable churches, which is a complex process that can be achieved following a large number of approaches, each one corresponding to a different level of accuracy, as presented in Figure 12 (Zizi et al. 2021).

As a result of an investigation performed by the World Bank Evalution Group, the cost of repairing due to natural hazards is rising and expecting to continually rise, making the risk reduction policies more important than ever. One of the simplest elements that consists of the base of the risk reduction strategies are the simplified assessment procedures that allows a quick screening of a certain area and a simplified vulnerability ranking which is convenient for multi-level decisional tool and further more detailed analysis and interventions (D'Amato, Laterza, and Diaz Fuentes 2020). The knowledge process addresses several aspects, such as simplified visual screening procedures for identifying the most vulnerable buildings and churches, innovative tools for processing and managing the data and integrated urban planning strategies for risk reduction (Pelà 2018).

The new urban planning policies recommend considering always a balance between design features and economic, social, and environmental aspects (Tsimplokoukou, Lamperti, and Negro 2014). This aspect is very important when designing new buildings, but assessing the emissions of existing ones, especially historical heritage buildings, is very difficult (Mazzarella 2015). A new procedure was developed by Prof. Bertolin, the Zero Emission Refurbishment method, which aims to reduce the carbon footprint of large-scale interventions on old building stocks. The methodology follows several steps, such as the assessment of the historic value of the investigated buildings, the assessment of the existing decay, recategorization, life cycle assessment, calculation of emissions, and payback approach, as illustrated in Figure 13 (Loli and Bertolin 2021).

This procedure is one of the few methodologies that links knowledge from experts in various disciplines and focuses on existing buildings. Moreover, it integrates muticriteria approaches and ensures at the same time long-term maintenance of existing buildings, to reduce the impact of climate change issues. The innovative approach highlights restoration and conservation principles that are valuable and must be respected, considering at the same time different levels of interventions and analyzing their impact in terms of gas emissions that should be compensated in one way or another (Bertolin and Loli 2018).

In the context of the most recent earthquakes in Europe and in the entire world, the development of new vulnerability assessment procedures that are easy to apply to a large number of buildings and churches should be considered a priority, contributing to a more sustainable and resilient environment (Ferreira et al. 2021). Moreover, a comprehensive assessment methodology that will consider also the sustainability aspects should be developed, for a more resilient risk reduction policy at urban scale.

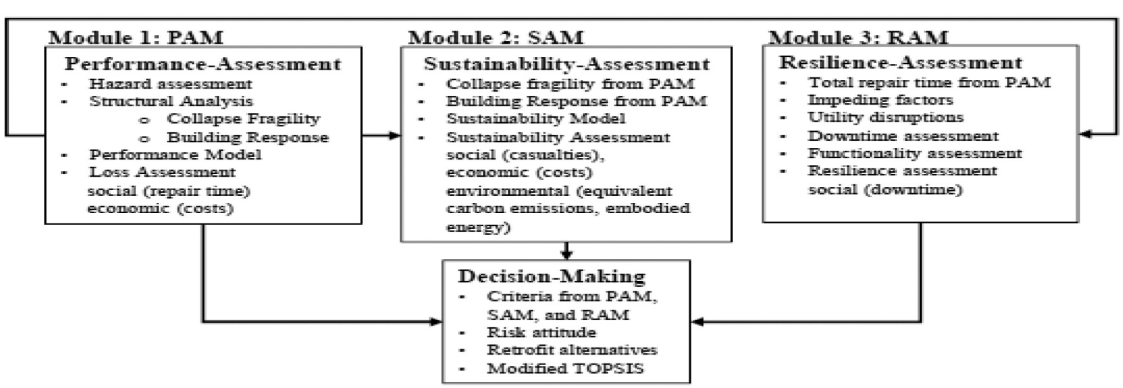


Figure 11. Multi-criteria decision-making framework for sustainable risk reduction process [22].

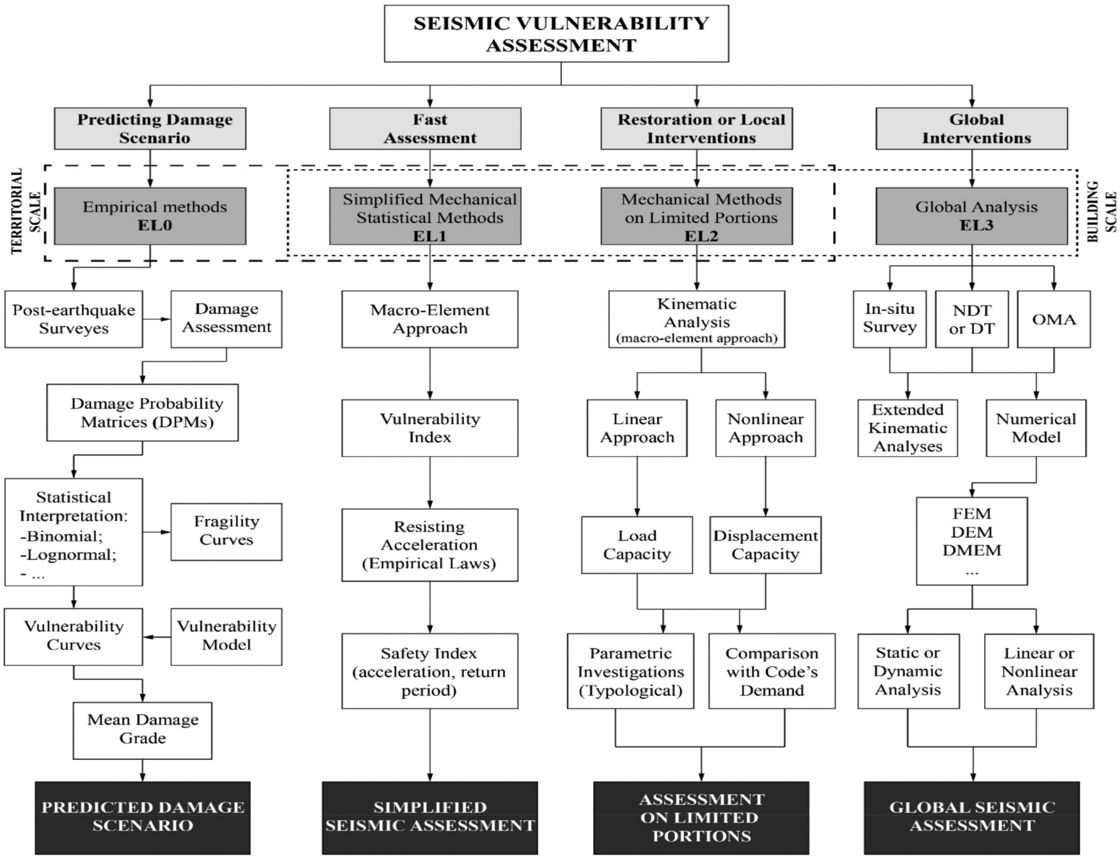


Figure 12. Approaches in the seismic vulnerability assessment process [15].

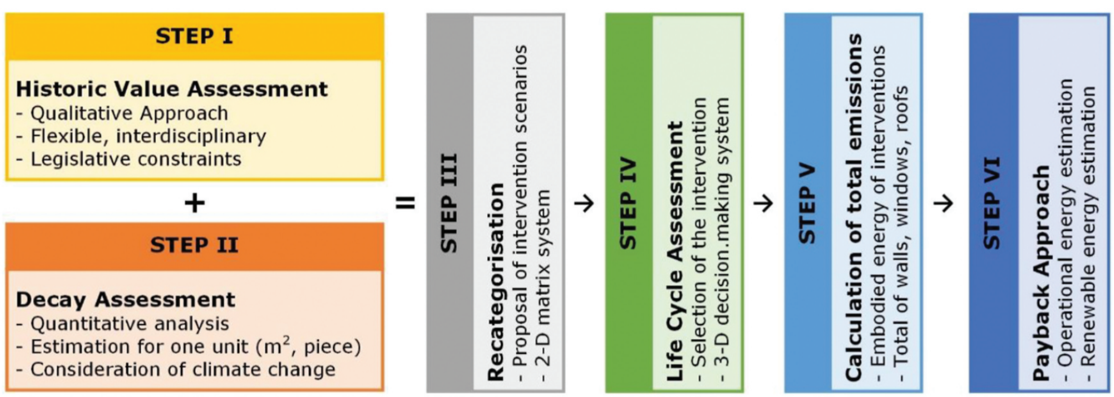


Figure 13. Methodology steps of the Zero Emission Refurbishment procedure for existing buildings and built areas (Loli and Bertolin 2021).

5. Conclusion

When comparing the results obtained following Romanian and Italian vulnerability assessment methodologies, there can be seen a good correlation of the vulnerability classification, with all methods indicating the Church in Cenad as the most vulnerable one, followed by the Church in Chizatau, the Church in Bocsa, then the one in Bencec, the Church in Beregsau, and the less vulnerable is the Church in Belint. The Romanian empiric vulnerability assessment methodology that takes into consideration also the cultural value proposed tends to underestimate 10–15% the seismic vulnerability of the investigated churches in terms of vulnerability indexes but estimates correctly the expected damage state (Figure 9). None of the investigated churches satisfies the LSLS verification.

The purpose of conducting urban disaster risk assessment is to manage and reduce the risk of disasters in urban areas by linking disaster risk analysis with urban vulnerability analysis to identify potential hazards, evaluate the potential impacts and risks associated with those hazards, and recommend effective countermeasures and strategies for risk reduction. The assessment can be used to make informed decisions and to prioritize resources to prevent or mitigate the negative effects of disasters on communities and urban environments (Shi et al. 2018).

Nowadays, finding and applying sustainable methods for the vulnerability assessment of heritage buildings represents a provocative aspect, because of the large number of uncertainties that come with historical constructions. Despite these challenges, preserving the architectural heritage should be one of the main priorities for the local authorities in cities and areas with cultural value, and identifying simplified procedures for risk reduction could help the process. The indication of those limitations in the field of vulnerability assessment of historical buildings and areas represents one of the main novelties of the present paper, as it highlights a very interesting research opportunity for future work.

Moreover, those simplified procedures should consider in the future not only structural, architectural-artistic, urbanistic, and socio-economic parameters but also sustainability aspects, to ensure a more resilient risk reduction policy. The importance of the sustainability aspect in the field of vulnerability assessment represents a research opportunity, as it will facilitate more resilient policies at territorial scale, with a better impact on the historical built environment.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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