

## METHODOLOGICAL REQUESTS FOR TRANSFORMING BUILDING STOCKS INTO AN EMS-98 CONSISTENT TYPOLOGY

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**Abstract:** *The harmonization of a building typology is a major task in the implementation of exposure-modelling techniques used in earthquake risk scenarios and damage prognosis. The reliability of the results depends on the consideration of uncertainties in the input dataset(s). For the evaluation of building stocks, completeness and accuracy are affected by survey forms used to collect the data and post-processing. In this direction, and using masonry structures as example, the quality of the units, the mortar and construction represent ambiguous characteristics if the typology in question is to be compared with the EMS-98 and no additional information is given. In such hypothetical scenario, a further analysis of the structural composition of the building stock is needed, and the dataset containing the information is to be scrutinized. Procedures to perform such elaboration are under discussion, without reaching a collective agreement. It is therefore the target of the paper to describe a methodological scheme to transform a highly complex and country-dependent taxonomy into a consistent and equivalent EMS-98 typology. The knowledge-based exposure modelling framework developed within TURNkey Project is presented enabling the implementation and transformation of various building taxonomies into a standardized one. Different case studies are selected recognizing different levels of data availability to define the initial stage of the proposed method. Datasets are evaluated according to their completeness and appropriateness for re-consideration. A minimum level of building information is defined to apply the methodology. The work-flow is then carried out using as case study the historical centre of L'Aquila with the building damage information from 2009 survey campaigns and the available descriptions qualified by recent survey techniques and available data access. Lastly, it is discussed how other taxonomies can be directed to the simple and robust EMS-98 classification scheme, and an "easy use".*

### 1 Introduction

The harmonization of a building typology is a major task in the implementation of exposure-modelling techniques used in earthquake risk scenarios and damage prognosis. The reliability of the results depends on the consideration of uncertainties in the input datasets and the details given to describe the structural characteristic of the considered building stock. With this in mind, and given the efforts among the scientific community to define a taxonomy adaptable to earthquake risk scenarios in any place of the world, the need of a common international ground is evident. Nonetheless, the idea itself comes with several challenges, being one of them the standardization of structural parameters used to define a typology where, here suggesting, the European Macroseismic Scale (Grünthal et al., 1998) taxonomy is to be used as basis.

Building types	Masonry		Reinforced concrete			Others		VC
	Rubble stone, fieldstone	Unreinforced, with manufactured stone	Frame without ERD	Wall without ERD	Steel structures	Steel structures	A	
Adobe (earth brick)	Frame with moderate ERD						Wall with moderate ERD	B
Simple stone			Reinforced or confined	Frame with high ERD	Wall with high ERD	C		
Massive stone	Timber structures					Timber structures	D	
					E			
				F				

Figure 1. TURNkey D4.1 color scheme for EMS-98 building types and vulnerability classes (Schwarz et al., 2021).

A methodological transformation of different case studies is here performed to obtain an EMS-98 comparable building typology. Datasets from building stock survey, reconnaissance campaigns and census are used to establish different knowledge levels that allow the identification of EMS-98 building types, with variations between each of the studied areas. The color scheme from TURNkey’s knowledge-based exposure modelling framework and methodology is used as basis (Schwarz et al., 2021). This paper intends to demonstrate how the characteristics of a building stock permit the definition of EMS-98 comparable typologies, on a first stage of analysis using the qualitative description of a structure. This research supports the creation of an international taxonomy that follows the principles of the EMS-98, as the study includes European and international cases. Further on, the results highlight the importance of future works to evaluate the ranges of possible vulnerability assignments when international building stocks are compared with the EMS-98 scheme.

## 2 European case study: L’Aquila, Italy

### 2.1 Target area

On April 6th 2009, an Mw 6.3 earthquake struck the municipality of L’Aquila, Italy, affecting an approximate of 80,000 residential buildings (U.S.G.S., 2022). Followed by four relevant aftershocks between 5.1 and 5.4 Mw, the seismic sequence has been object of several studies for the past decade. Particular attention has been given to the historical center of the city of L’Aquila with aims of following its recovery speed and recognizing the factors that contributed to the observed damages. In this direction, the Da.D.O. database (Dolce et al., 2019) contains the collection of several survey campaigns that took place in Italy after relevant earthquakes, starting in 1980. Overall, the structural characteristics of buildings exposed and inspected were compiled following the structure of different inspection questionnaires depending on the year of seismic event. Supported by the Italian Civil Protection Department, the database also includes social-economical characteristics such as the use of the building.

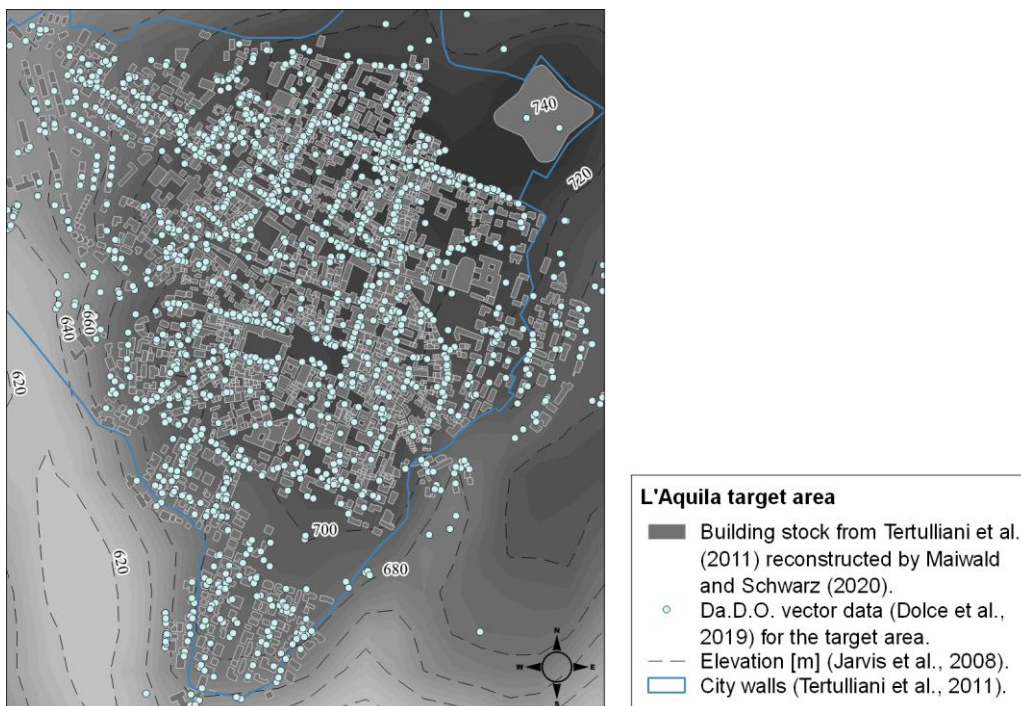


Figure 2. L’Aquila city centre, target area and data points from Dolce et al. (2019).

**Masonry**

Vertical structures		Reinforcement			Presence of tie-beams		Horizontal structures				
Bad quality	Good quality	Yes	No	Variable	Yes	No	Beams			Vaults	
							Flexible	Semi-rigid	Rigid	With tie-rods	Without tie-rods

**Reinforce concrete**

Vertical structures		Details*			<b>For all structures</b>			
Frame	Walls	Frame over masonry	Masonry over frame	Masonry & frames (parallel)	Year of construction	Year of retrofit	Number of storeys	Regularity

Notes:

\* Classification also available for Mixed frame - masonry, regardless of frame material (reinforced concrete, timber or steel).

Figure 3. Structural characteristics given by Da.D.O. (Dolce et al., 2019) for typology definition.

For L'Aquila, a total of 74,049 buildings are included in the database, with only 3,947 buildings found within the target area (see Figure 2) here assumed equal to the region investigated by Tertulliani et al. (2011). The information is given by Da.D.O. as data entries in a cvs-file, and therefore a punctual distribution of the buildings along the area can be obtained as shown in Figure 2. With aims of comparison, the reconstruction of the building stock made by Maiwald and Schwarz (2020) has been included in the figure. An overview of the most relevant characteristics from the L'Aquila event, that can be used for the definition of building types, is presented in Figure 3.

Table 1. Existing studies relating Italian building types to EMS-98.

Material	Reference	Taxonomy	Vulnerability classes	Taxonomy conversion <sup>1)</sup>
Masonry	(Perelli et al., 2019)	ISTAT S.A.V.E. <sup>2)</sup>	EMS-98	No
	(Lagomarsino et al., 2021)	ISTAT <sup>3)</sup> EMS-98 <sup>4)</sup>	EMS-98	No
	(Rosti et al., 2021b)	ISTAT RISK-EU <sup>5)</sup>	EMS-98 IRMA <sup>6)</sup>	No
	(Zuccaro et al., 2021)	ISTAT	EMS-98 IRMA	No
	(Donà et al., 2021)	ISTAT	ND <sup>7)</sup>	No
	(Del Gaudio et al., 2021)	AeDES Proposal <sup>8)</sup>	ND	No
Reinforced concrete	(Borzi et al., 2021a)	ISTAT	EMS-98 IRMA	No
	(Rosti et al., 2021a)	ISTAT	EMS-98	No
General	(Nicodemo et al., 2020)	GEM <sup>9)</sup>	EMS-98	Yes
	(Dolce et al., 2021)	ISTAT	EMS-98	No

**Notes:**<sup>1)</sup> From AeDES to EMS-98 building types.<sup>2)</sup> S.A.V.E., Updated tools for seismic vulnerability evaluation of the Italian real estate and of urban systems (Zuccaro and Cacace, 2015).<sup>3)</sup> ISTAT, Italy's national census database.<sup>4)</sup> Referenced without specification of conversion from ISTAT to EMS-98.<sup>5)</sup> Milutinovic and Trendafiloski (2003).<sup>6)</sup> IRMA, Italian Risk Maps platform (Borzi et al., 2021b).<sup>7)</sup> ND, Not discussed in the study.<sup>8)</sup> Classification proposed for the mentioned study.<sup>9)</sup> GEM, Global Earthquake Model (Brzev et al., 2013).

The analysis of fragility curves for Italian residential buildings performed in Da Porto et al. (2021) was taken as starting point for the identification of existing studies about the database and the target area. The elaboration of Table 1 presents the scientific literature found regarding the topic, where some of the studies have a national consideration of building stock based on census information, some others focused on the target area. A comparison of the taxonomy used in each of them is shown as well as an evaluation to distinguish if the study presents or not a conversion scheme comparing the building characteristics described by the AeDES 06/2008 form (Baggio et al., 2007) used for Da.D.O. (Dolce et al., 2019) and the building types established by the EMS-98 (Grünthal et al., 1998).

The review presented in Table 1 suggest the works from Nicodemo et al. (2020) are close to the objective of the present study, by transforming the typological information given by the AeDES 06/2008 form to a GEM taxonomy (Brzev et al., 2013), followed by a conversion to EMS-98 building types, all through a score-based method (Pittore et al., 2018). A simplified method for such transformation is here proposed, taking as starting point the building types used by the studies discussed in Table 1, and the first two stages of TURNkey's knowledge-based exposure modelling framework: exposure and data availability (Schwarz et al., 2021).

## 2.2 Proposed transformation into EMS-98 comparable typology

Based on the information given by Da.D.O. (2019), the findings from Table 1 and the studies performed by Lamadrid et al. (2023), an EMS-98 consistent typology for the target area is hereby studied. Following the descriptions given by Baggio et al. (2007) about the building characteristics given by the AeDES survey form three knowledge levels were established to define a building type. For knowledge level 1, material was taken as reference and classified. For knowledge level 2, the description of vertical structural elements was used.

Particularly for bad quality masonry, there is no additional information given by Da.D.O. regarding the differentiation between rubble stones, squared simple stones or the presence of pebbles. It is here acknowledged, that the year of construction could be considered to distinguish the type of masonry units in bad quality masonry.

Following Del Gaudio et al. (2021), the ranges given by Da.D.O. and the description of EMS-98 building types, any bad quality masonry built before 1919 is considered as rubble stones and pebbles.

Table 2. Code level according to year of construction.

Year of construction	Proposed Code Level	Existing schemes <sup>1)</sup>	Comments <sup>2)</sup>
<1919	Pre-Code (PC)	Group 1	1915 – Consideration of seismic loads only for moment resisting structures.
1919-1945	Low Code (LC)	Group 2	1927 – Application of seismic design depends on seismic zones.
1946-1961		Group 3	1935 – Update for ratio between horizontal forces and storey weight.
1962-1971	Low Code + (LC+)	Group 4	1962 – Ratio between the base shear design and the weight of the building updated.
1972-1981			1975 – Introduction of response spectrum.
1982-1991	Moderate Code (MC)	Group 5	1984 – Seismic zones updated.
1992-2001			1986 – Seismic coefficients updated. 1987 – Seismic design of masonry mandatory.
>2001	Moderate to High Code (MHC)		1996 – Introduction of limit state design method. 2003 – Seismic zones updated. – Mandatory limit state design method.

### Notes:

<sup>1)</sup> Based on year of construction, examples can be found in references from Table 1.

<sup>2)</sup> Adapted from Del Gaudio et al. (2021).

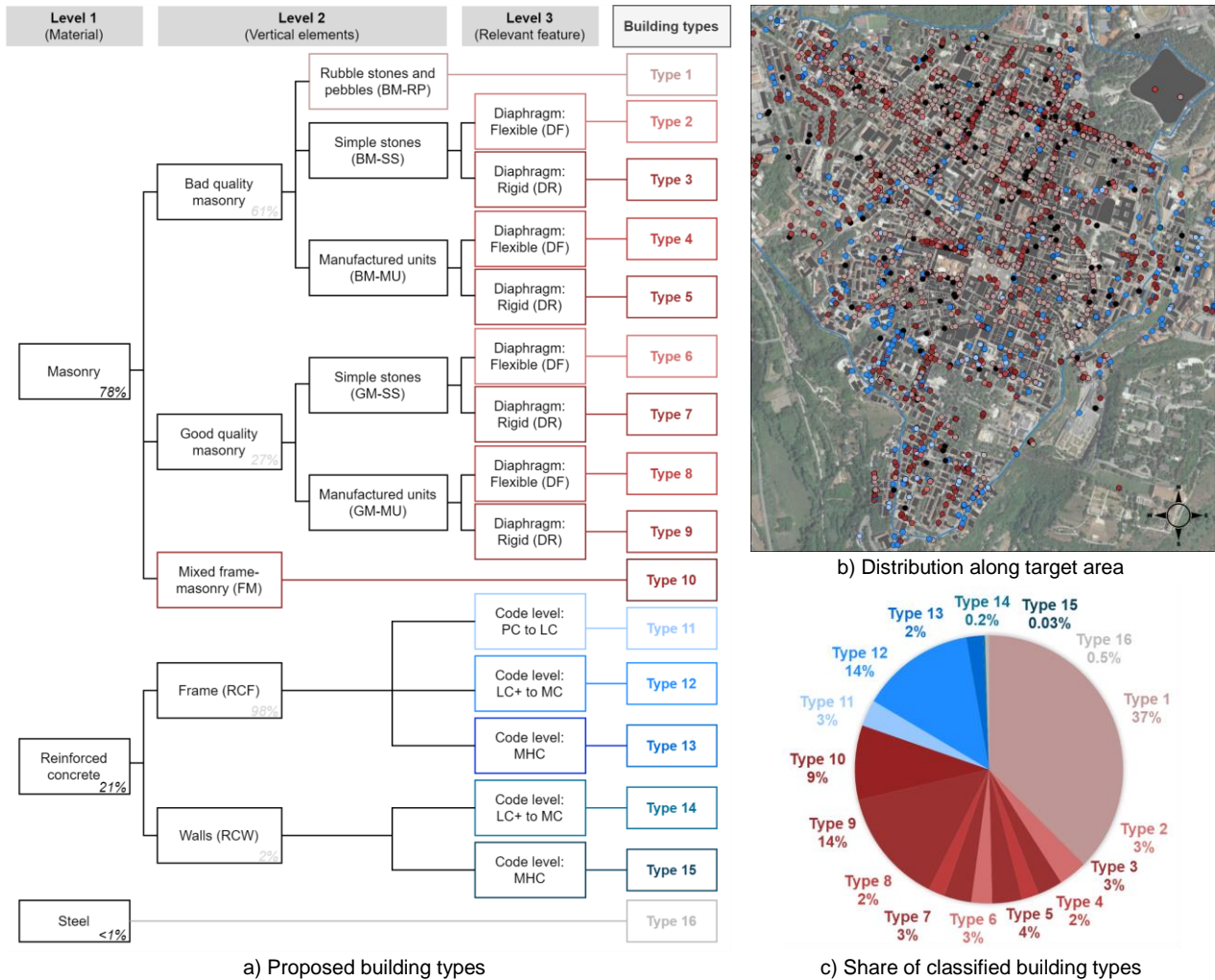


Figure 4. EMS-98 consistent typology for target area.

As the use of pebbles was forbidden after 1935, any bad quality masonry built within the range of 1919 and 1945 is here considered as simple stone, as no other parameter can be used to distinguish the use of stones from the use of manufactured masonry units. Bad quality masonry built after such range is considered as unreinforced (i.e., unreinforced masonry with manufactured stone units or with RC floors depending on further knowledge levels). For good quality masonry all constructions done before 1919 are considered as simple stone while the rest is considered manufactured masonry units.

Knowledge level 3 describes a building characteristic used by the EMS-98 to distinguish between different types of basic structures. The type of inter-storey diaphragm (i.e., horizontal elements for the AeDES form and for Da.D.O.) is used for masonry buildings, while the level of earthquake-resistant design (ERD) is used for reinforced concrete structures. For diaphragms, only two classifications were considered, the presence of semi-rigid or rigid diaphragms was distinguished from flexible diaphragms as the earlier represent a considerable improvement to the seismic response of a masonry structure.

The definition of code levels used for reinforced concrete structures is shown in Table 2 along with the ranges given by Da.D.O. regarding the year of construction. The code level classification was done based on the evolution of seismic codes described by Del Gaudio et al. (2021). It is worth noting that the references from Table 1 provide variations on the aggrupation of structures due to year of construction, however the comments given in Table 2 indicate the modifications considered in the present study. As the mentioned references might use such classification as final taxonomy, the present study aims for a more detailed differentiation.

Considering the aforementioned levels, the data from the Da.D.O. dataset was transformed into EMS-98 comparable taxonomy as shown in Figure 4a, with a total of 16 building types, a wider taxonomy than the one presented by Lamadrid et al. (2023). The differences for the increase of building types reside in two facts.

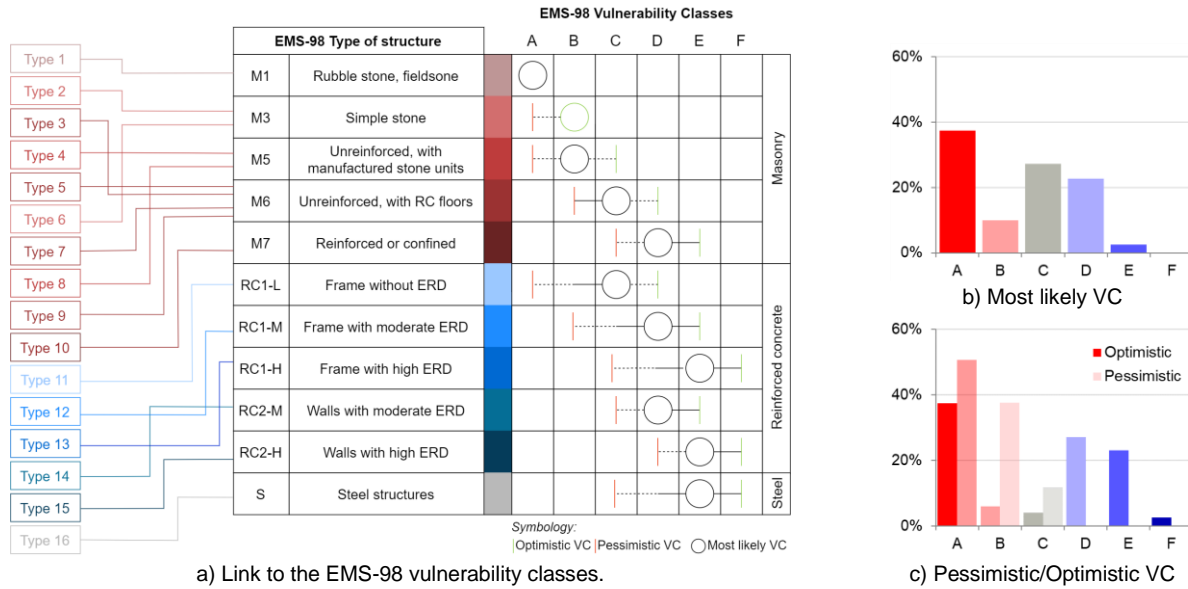


Figure 5. Building types within the area of interest.

First, for knowledge level 2 Lamadrid et al. (2023) does not distinguish between masonry with rubble stone, simple stone or manufactured units; secondly the code level proposed by Lamadrid et al. (2023) was based on Crowley et al. (2020). Additionally, the distribution of the building types along the studied area is presented in Figure 4b while their share is shown in Figure 4c. From both it can be observed and corroborated that the composition of the area is dominated by masonry with bad quality units built before 1919.

Further on, each building type is correlated to the EMS-98 types of structures. In Figure 5a, such relation is graphically represented with possible ranges of vulnerability classes being marked and their limits as optimistic (green line), pessimistic (red line) and the most probable assignment (black circle). On one extreme the optimistic assignment of a vulnerability class assumes the building will have the optimal response when subjected to seismic action, given its structural characteristics. For most types, this is translated into lower vulnerability and the reduction of one vulnerability class from the most likely one. On the other extreme, the pessimistic assignment assumes the seismic response of the building will be the most unfavourable. Exception to such behaviours is the EMS-98 M1 type, were no variations of the vulnerability are expected.

The comparison of shares from vulnerability classes considering the different assignment was performed to evaluate the changes in composition, following the approach from Abrahamczyk et al. (2013). Figure 5b presents the distribution considering the most likely assignment, while the implementation of the optimistic and pessimistic assignments is presented in Figure 5c. In all cases, the vulnerability class A is found dominant, as building type 1 has the higher share among the building stock. Such result evidences the need of the implementation of an assignment based on engineering criteria where, in addition to scheme presented in Figure 4a, further knowledge levels are used to discern the best possible assignment that would describe the seismic response of a building given all the information provided by the consulted dataset. It is also important to highlight that, for an EMS-98 comparable typology it would be sufficient to distinguish from the 11 building types which describe the building stock from the area, however when it comes to an engineering assignment of vulnerability classes, it is clear that the distinctions made in Figure 5a are necessary. In this direction, three additional knowledge levels are here considered for the modification of the most likely vulnerability class, within the ranges given by EMS-98 but considering the variations on seismic response without falling into non-flexible criteria, as it done when an optimistic or pessimistic assignment is considered.

For knowledge level 4, the height of the building was considered following the classification done by Lagomarsino et al. (2021), from 1 to 2 storeys a low height class (L) was assigned, from 3 to 5 storeys a medium height class (M) and for buildings with more than 5 storeys a high height class (H) was assigned. For the fifth level, the regularity in plan and elevation was taken as given by Da.D.O. as regular (R), irregular (I) and unknown (U). Lastly, for those structures with masonry units (i.e., masonry structures or reinforced concrete frames with infills) the regularity of the unit’s layout was considered, also as given by Da.D.O. as regular (R), irregular (I) and unknown (U).

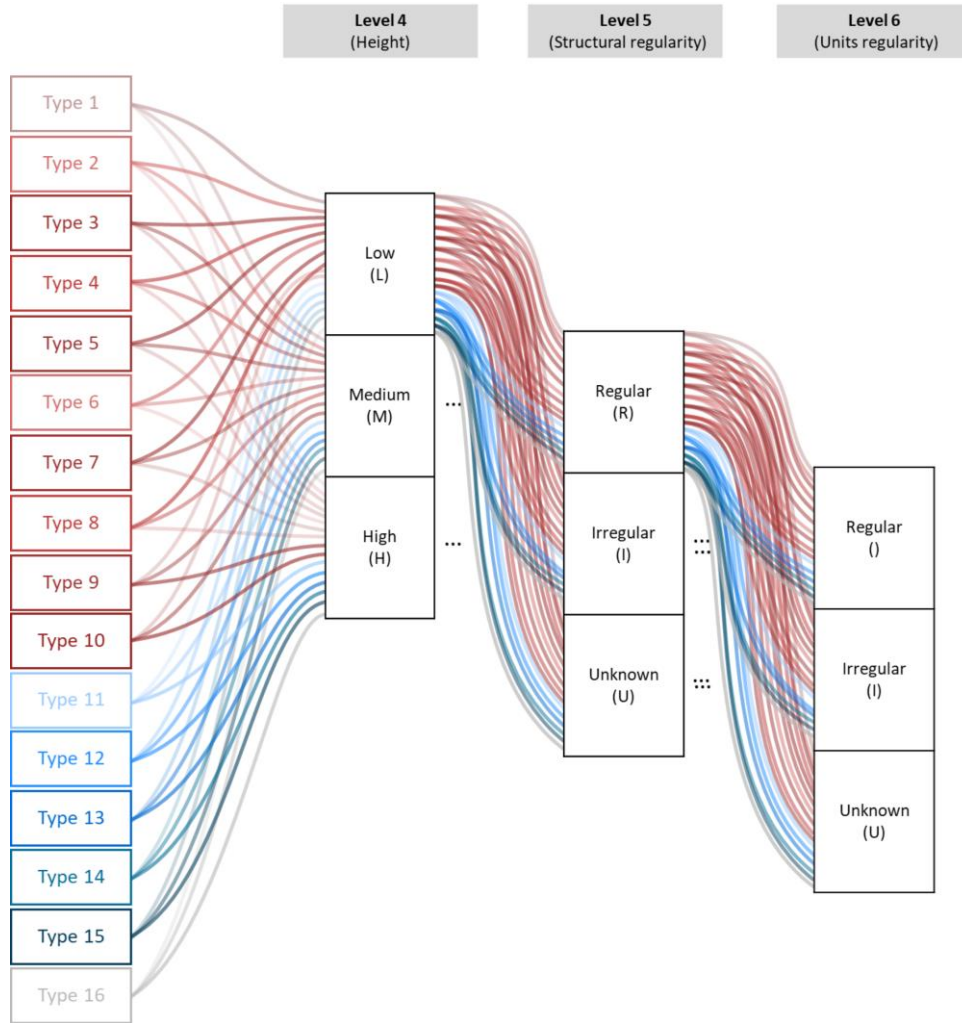


Figure 6. Possible combinations of relevant building features for the assignment of an EMS-98 vulnerability.

Based on the discussed characteristics and knowledge levels, an assignment of vulnerability classes is proposed with a graphical illustration of the possible combinations along with the final assignments shown in Figure 6. Such proposal represents one from the numerous possibilities that can come from the assignment of vulnerability classes using a flexible criterion, which is often described as a vulnerability assignment based on experience or engineering assignment.

The details of the proposal are presented in Figure 7 showing the building type, the characteristics considered for modification of the VC and an overview of the final VC shares. For most types of masonry structures the vulnerability assignment was considered variable, between classes A and C. With the exception of Type 10, where a VC D was assigned to those reinforced or confined masonry structures with 1 or 2 storeys, regularity in plan and elevation and regular layouts of masonry units.

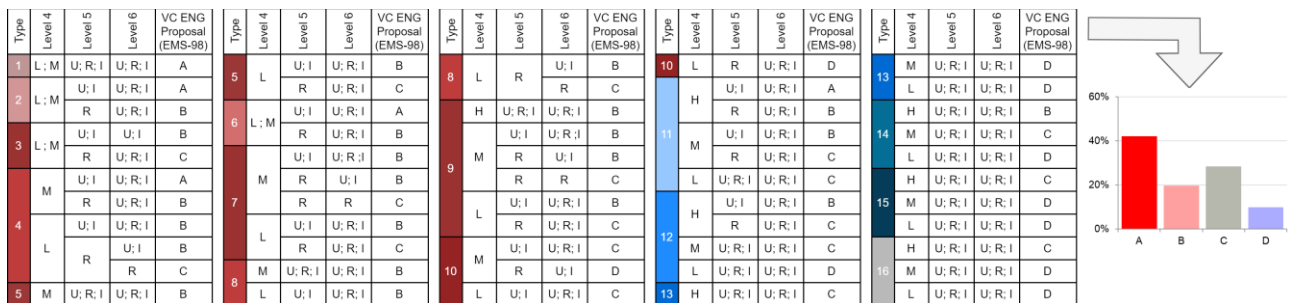


Figure 7. Proposal for vulnerability assignments based on EMS-98 most likely VC classes considering secondary building characteristics.

Figure 7 assignments contrasts with the equivalence proposed by Dolce et al. (2019) where class D is reserved for reinforced concrete and steel buildings and VC A to B are reserved for masonry (see building type 10 to building type 16). Nonetheless, some of the criteria from Dolce et al. (2019) was implemented with variations according to the buildings' secondary characteristics (Figure 5). Overall, VC D was considered as the highest vulnerability class found in the studied building stock.

With the selected criteria, the resulting shares per VC show significant variations from the criteria used in Figure 5b and Figure 5c. Additionally, the composition of the building stock diverges from the one presented by Tertulliani et al. (2011) with a closer similarity to the composition given with the Dolce et al. (2019) criteria.

These results evidence the fact that variations on the vulnerability of a building stock are expected when different parts incorporate different considerations on the assignments based on experience, even if the same scheme is being applied. Further discussion on this variations and alternative proposals for the assignment of vulnerability classes following the EMS-98 can be found in Lamadrid et al. (2023).

### 3 Transformation of international building stocks

#### 3.1 Case study: Erbil, Iraq

Erbil, the capital city from the Kurdistan Region of Iraq is bounded by several seismic faults (Jassim and Goff, 2006) and composed of a diverse building stock given its historic relevance and continuous population growth (Ritchie et al., 2023). In 2022, a documentation of the building stock data was performed following the scheme from Schwarz et al. (2019). Later on, with a preliminary overview of results discussed by Hasan et al. (2024) the collected information was used for the definition of building types as done in section 2.2, starting by the identification of basic knowledge levels that would lead to the transformation of the building stock into an EMS-98 comparable typology, resulting in Figure 8.

Knowledge level 1 was considered to describe construction material as done in Figure 4a. For knowledge level 2, no further distinction had to be done to identify masonry units as the included data already featured the characteristic distinguishing 4 different cases of masonry units: stones, bricks, cement blocks and unknown material. As relevant characteristic in knowledge level 3, masonry structures were assumed to include rigid diaphragms, as the use of reinforced concrete slabs is a common practice within the city.

For reinforced concrete structures, three different ERD levels were considered. Following the first official seismic code in Iraq published in 1997, anything built before this year was considered Pre-Code level, even though a seismic load had been already considered in design codes since 1987.

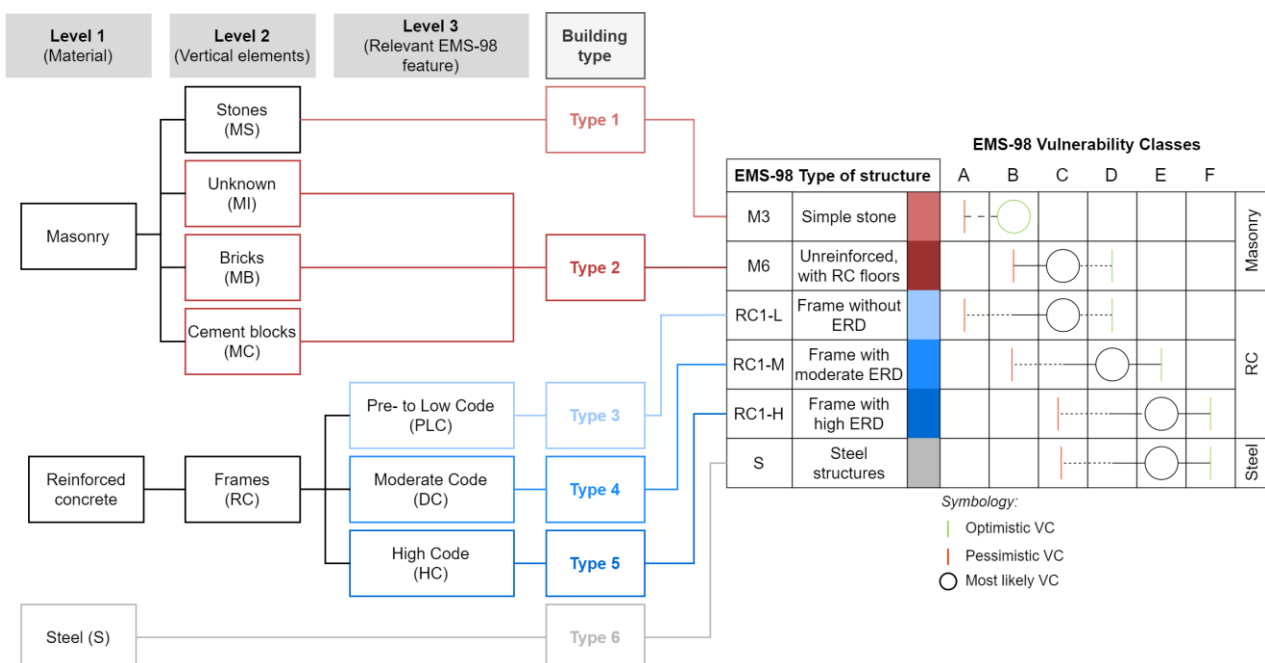


Figure 8. Proposal for building types and vulnerability classes and link to EMS-98 scheme.

The 1997 code version included seismic zones of the national territory. Construction dated between 1997 and 2014 were considered with low code level as in 2014 and updated version of the Iraqi seismic code was published, including mapped acceleration.

The most recent code was published in 2017, and therefore here assumed as the highest code level possible. Structures built from 2014 to 2017 were identified with a moderate code level. As a result, 6 types of structures were identified within the studied sample, with masonry structures with an equivalent EMS-98 type equal to M6 being the dominant type (i.e., type 2 in Figure 8). Such classifications indicate a suitable assignment of EMS-98, however it is to be discussed if the ranges of vulnerability classes are to remain equal, as the behaviour of material and the construction process might differ from the European ones. In this direction, further studies would be necessary to compare the structural response of the building stock during seismic events.

### 3.2 Case study: Hveragerdi, Iceland

In 2000, two earthquakes affected the residential buildings from Hveragerdi, Iceland. Both seismic events with a Mw 6.5 and an interval of four days from each other (EQ1: June 17th 2000, depth 6.3 km; EQ2: June 21st 2000, depth 5.3 km). With considerable damage in inhabited areas within 20 km of the epicentres, the data collected for the building stock characteristics and the damage observed during the earthquakes makes the area suitable for implementation of a methodological transformation of building stock data into an EMS-98 comparable typology. Such transformation was developed by Schwarz et al. (2021) within the TURNkey framework. The data was pre-processed by Darzi et al. (2020), with building characteristics such as material, number of storeys, year of construction and lateral load resisting system. Such features were used to classify the buildings according to the SERA taxonomy (Crowley et al., 2020).

Following the correlations presented by Abrahamczyk et al. (2021), the TURNkey D4.1 report (Schwarz et al., 2021) correlated the identified SERA building type to EMS-98 as shown in Figure 9. Difficulties were found to distinguish the ERD level for reinforced concrete walls, and therefore no direct conversion was given for CR/LWAL/HEX:1-3 and CR/LWAL/HEX:4. Nonetheless, the year of construction could be used for further discretization of the types, and the transformation is to be refined. Buildings where no information was given were neglected from the analysis.

Lastly, it is worth mentioning that one SERA building type was found without equivalence of existing EMS-98 building types (SRC/LWAL/HEX:2), nonetheless its incorporation is considered and included in Figure 9 with the vulnerability range suggested by Schwarz et al. (2021) without distinguishing the probable ranges established by the EMS-98.

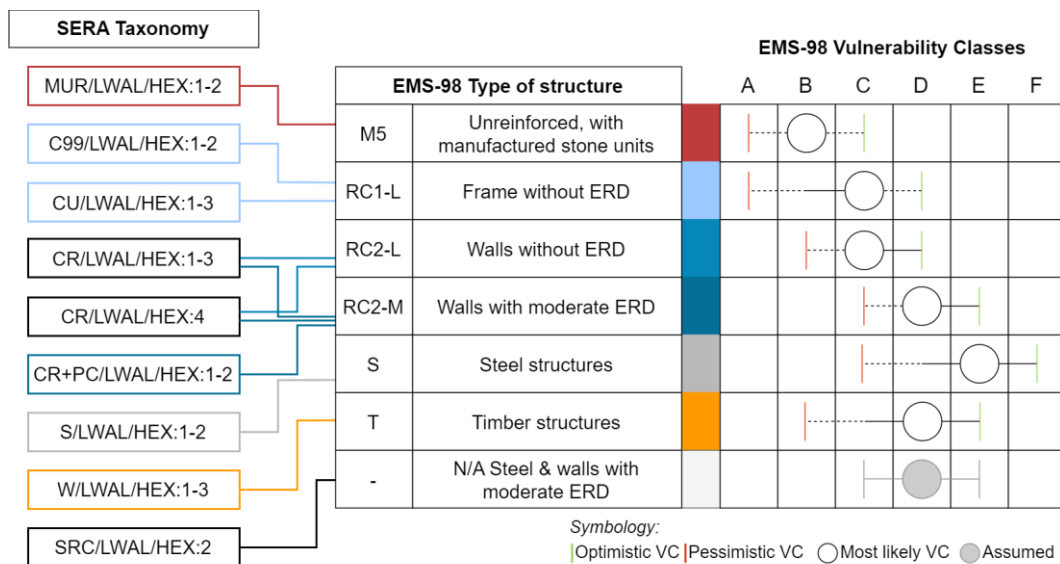


Figure 9. Building types within Hveragerdi (Iceland) and their relation to the EMS-98 vulnerability classes.

## 4 Discussion

As defined by the knowledge-based modelling framework (Schwarz *et al.*, 2021), the definition of building types depends on great extent on the level of data availability, particularly on the level of detail found in the description of the studied building stock. The results from the analysed case studies show that the minimum requirements for an EMS-98 comparable taxonomy should include 3 key knowledge levels or characteristics: material (level 1), description of vertical structural elements (level 2) and a key feature (level 3). Being the last one valid only for masonry and concrete structures.

In the case of masonry structures, the description of units as vertical structural elements is an essential feature impacting the EMS-98 building classification scheme. Unfortunately, this is seldomly included in a national census as it requires a detailed survey of a building. It then becomes the task of the researcher to investigate the architectural history of the target area, and assume other parameters can be used to define the type of masonry units (as done in section 2.2). As an additional key feature of masonry buildings, the type of diaphragm is rarely register when it comes to national census data. In some cases, it can be found replaced with roofs material information. Therefore, recognition of the traditional construction practices of the studied area is necessary to establish a distinction between EMS-98 building types (see section 3.1).

For reinforced concrete (RC) structures the description of vertical structural elements is often clear and distinguished between walls and frames; in contrast, the code level used as in the EMS-98 to distinguish different RC types (referred during the present study as knowledge level to classify RC structures) implies studying the evolution of seismic codes from the studied area. This rises the question on what identifies a code with a low, moderated or high level, when the ERD is being evaluated, with further discussion of the topic addressed by Haweyou *et al.* (2024).

It is clear that one of the purposes of existing taxonomies, such as SERA or GEM, is to establish uniform nomenclatures and typologies. These are broad enough to evaluate building stocks from different areas of the world and facilitate the comparison between them. Additionally, it is evident that such taxonomies provide standardized classification schemes which allow final vulnerability assignments that can be used in probabilistic seismic risk analysis or earthquake scenarios. In contrast, one of the most significant objectives from the EMS-98 is to provide simplified classification schemes to describe a macroseismic intensity. Most importantly, schemes that can be implemented through practical observations. This without the complexity that implies a focus on civil engineering or seismology, as the final target group comprehends other possible users that may not be experts in the matter.

Keeping in mind such simplicity, it can be discussed that complex taxonomies cannot always lead to a straightforward equivalent of EMS-98 building types. Two examples of this situation were found in this study (Figure 9). The first one refers to the absence of an equivalent type (i.e., SRC/LWAL/HEX:1-3), as the load bearing system might not be included in the EMS-98. The second example denotes insufficient information for a correlation. Specifically, two SERA types (i.e., CR/LWAL/HEX:1-3 and CR/LWAL/HEX:4) cannot be redirected to one EMS-98 type since the year of construction is not included in the nomenclature nor is the level of ERD given.

Pursuant to the current EMS-98 scope, a simplified method to transform complex taxonomies would be beneficial for the definition of an international scheme. Without question, building types currently not covered are to be added. However, given the aspects here evaluated, only generalized types are suggested taking as basis the EMS-98 classification criteria.

Further on, the methodology followed in the present study along with the definition of parameters for the assignment of vulnerability classes could be taken as a contribution to the development of the World Housing Encyclopedia (EERI and IAEE, 2009). Moreover, a link to Intensity assignments within the sometimes-referred EQ experience becomes possible and could be addressed in future studies.

## 5 Conclusions

Through the present research different datasets were evaluated with the aim of defining a methodological procedure to transform a building typology into an EMS-98 comparable taxonomy. A graphical representation of the method has been presenting, with results showing that, regardless of geographical location of the building stock, with basic physical characteristics of the structures it is possible to define a building typology

comparable to the descriptions given by the EMS-98. Nonetheless, it is evident that due to different material properties and construction processes, different ranges for vulnerability classes are to be expected when the analysed building stock is located outside the European continent. Consequently, further research is needed where the damage observed in the analysed building stock is considered to evaluate if changes on vulnerability ranges are actually observed.

## 6 Acknowledgements

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The presented results are documenting the outcome of ongoing studies to test the knowledge-based exposure modelling framework and the reliability of damage prognosis following the developed seismic risk assessment procedures. These studies were partially supported by DFG funding under grant No. SCHW 662/4-4.

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## 7 References

- Abrahamczyk L., Schwarz J., Haweyou, M. (2021). Extension of the EMS-98 Vulnerability Table integrating recently proposed Building Type Taxonomies (submitted). *Earthquake Spectra*.
- Abrahamczyk L., Schwarz J., Langhammer T., Genes M., Bikce M., Kacin S., Gülkan P. (2013). Seismic Risk Assessment and Mitigation in the Antakya-Maras Region (SERAMAR): Empirical Studies on the basis of EMS-98. *Earthquake Spectra*, 29(3): 683–704. doi: 10.1193/1.4000163
- Baggio C., Bernardini A., Colozza R., Corazza L., Bella M.D., Pasquale G. D., Dolce M., Goretti A., Martinelli A., Orsini G., Papa F., Zuccaro G. (2007). *Field Manual for post-earthquake damage and safety assessment and short-term countermeasures (AeDES)* (M. Rota & A. Goretti, Trans.; JRC37914; JRC Scientific and Technical Reports, 100 pages). European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen.
- Borzi B., Faravelli M., Di Meo A. (2021a). Application of the SP-BELA methodology to RC residential buildings in Italy to produce seismic risk maps for the national risk assessment. *Bulletin of Earthquake Engineering*, 19(8): 3185–3208. doi: 10.1007/s10518-020-00953-6
- Borzi B., Onida M., Faravelli M., Polli D., Pagano M., Quaroni D., Cantoni A., Speranza E., Moroni C. (2021b). IRMA platform for the calculation of damages and risks of Italian residential buildings. *Bulletin of Earthquake Engineering*, 19(8): 3033–3055. doi: 10.1007/s10518-020-00924-x
- Brzev S., Scawthorn C., Charleson A.W., Allen L., Greene M., Jaiswal K., Silva V. (2013). *GEM Building Taxonomy Version 2.0*. GEM Technical Report 2013-02. doi: 10.13117/GEM.EXP-MOD.TR2013.02
- Crowley H., Despotaki V., Rodrigues D., Silva V., Toma-Danila D., Riga E., Karatzetzou A., Fotopoulou S., Zugic Z., Sousa L., Ozcebe S., Gamba P. (2020). Exposure model for European seismic risk assessment. *Earthquake Spectra*, 36(1): 252–273. doi: 10.1177/8755293020919429
- Da Porto F., Donà M., Rosti A., Rota M., Lagomarsino S., Cattari S., Borzi B., Onida M., De Gregorio D., Perelli F.L., Del Gaudio C., Ricci P., Speranza E. (2021). Comparative analysis of the fragility curves for Italian residential masonry and RC buildings. *Bulletin of Earthquake Engineering*, 19(8): 3209–3252. doi: 10.1007/s10518-021-01120-1
- Darzi A., Bessason B., Halldorsson B. (2020). *Building Exposure Data for Husavik and Hveragerdi (TB3), TURNkey-T4.1-Memo-TB3 Building Exposure*. SIGILLUM University, Iceland.
- Del Gaudio C., Scala S.A., Ricci P., Verderame G.M. (2021). Evolution of the seismic vulnerability of masonry buildings based on the damage data from L’Aquila 2009 event. *Bulletin of Earthquake Engineering*, 19(11): 4435–4470. doi: 10.1007/s10518-021-01132-x
- Dolce M., Prota A., Borzi B., Da Porto F., Lagomarsino S., Magenes G., Moroni C., Penna A., Polese M., Speranza E., Verderame G.M., Zuccaro G. (2021). Seismic risk assessment of residential buildings in Italy. *Bulletin of Earthquake Engineering*, 19(8): 2999–3032. doi: 10.1007/s10518-020-01009-5
- Dolce M., Speranza E., Giordano F., Borzi B., Bocchi F., Conte C., Di Meo A., Faravelli M., Pascale B. (2019). Observed damage database of past Italian earthquakes: The Da.D.O. WebGIS. *Bollettino Di Geofisica Teorica Ed Applicata.*, 60(2): 141–164. doi: 10.4430/bgta0254

- Donà M., Carpanese P., Follador V., Sbrogiò L., Da Porto F. (2021). Mechanics-based fragility curves for Italian residential URM buildings. *Bulletin of Earthquake Engineering*, 19(8): 3099–3127. doi: 10.1007/s10518-020-00928-7
- EERI and IAEE (2009). *World Housing Encyclopedia (WHE)*. <https://www.world-housing.net/>
- Grünthal G., Musson R.M.W., Schwarz J., Stucchi M. (1998). *European Macroseismic Scale 1998 (Vol. 15)*. Cahiers du Centre Européen de Géodynamique et de Sismologie, Luxembourg.
- Hasan P., Lamadrid L.F.G., Abrahamczyk L., Jamal B., Saeed N.M., Schwarz J. (2024). Empirical seismic assessment of urban settlements in developing countries: Case study Erbil (Iraq). *18th World Conference Earthquake Engineering (18WCEE)*. Milan, Italy.
- Haweyou M., Schwarz J., Abrahamczyk L., Wenk Th. (2024). Challenges in damage prognosis for RC structures concerning the level of earthquake-resistant design. *18th World Conference Earthquake Engineering (18WCEE)*. Milan, Italy.
- Jassim S.Z., Goff J.C. (Eds.). (2006). *Geology of Iraq (First Edition)*. Dolin, Hlavni 2732, Prague and Moravian Museum, Zely trh 6.
- Lagomarsino S., Cattari S., Ottonelli D. (2021). The heuristic vulnerability model: Fragility curves for masonry buildings. *Bulletin of Earthquake Engineering*, 19(8), 3129–3163. doi: 10.1007/s10518-021-01063-7
- Lamadrid L.F.G., Schwarz J., Maiwald H. (2023). The intrinsic problems in EQ damage prognosis: The experience from a systematic evaluation of L'Aquila databases and different Levels of Data Availability (Under review). *Bulletin of Earthquake Engineering*. doi: 10.21203/rs.3.rs-3597218/v1
- Maiwald H., Schwarz J. (2020). Simulative Earthquake Damage Modelling Based on EMS-98 – Reliability and Predictability. Paper N°C000152, 12. *17th World Conference on Earthquake Engineering (17WCEE)*. Sendai, Japan
- Milutinovic Z., Trendafiloski G. (2003). *RISK-UE WPA Handbook: Vulnerability of current buildings (RISK-UE: An Advanced Approach to Earthquake Risk Scenarios with Applications to Different European)*. European Commission.
- Nicodemo G., Pittore M., Masi A., Manfredi V. (2020). Modelling exposure and vulnerability from post-earthquake survey data with risk-oriented taxonomies: AeDES form, GEM taxonomy and EMS-98 typologies. *International Journal of Disaster Risk Reduction*, 50, 101894. doi: 10.1016/j.ijdr.2020.101894
- Perelli F.L., De Gregorio D., Cacace F., Zuccaro G. (2019). Empirical vulnerability curves for Italian masonry buildings. *7th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2015)*. 1745–1758. Crete, Greece: National Technical University of Athens (NTUA).
- Pittore M., Haas M., Megalooikonomou K.G. (2018). Risk-Oriented, Bottom-Up Modelling of Building Portfolios With Faceted Taxonomies. *Frontiers in Built Environment*, 4:41.
- Ritchie H., Rodés-Guirao L., Mathieu E., Gerber M., Ortiz-Ospina E., Hasell J., Roser M. (2023). *Population Growth*. Our World in Data, World Population Prospects 2022. Retrieved from: <https://ourworldindata.org/population-growth>
- Rosti A., Del Gaudio C., Rota M., Ricci P., Di Ludovico M., Penna A., Verderame G.M. (2021a). Empirical fragility curves for Italian residential RC buildings. *Bulletin of Earthquake Engineering*, 19(8): 3165–3183. doi: 10.1007/s10518-020-00971-4
- Rosti A., Rota M., Penna A. (2021b). Empirical fragility curves for Italian URM buildings. *Bulletin of Earthquake Engineering*, 19(8): 3057–3076. doi: 10.1007/s10518-020-00845-9
- Schwarz J., Abrahamczyk L., Hadidian N., Kaufmann C. (2021). *TURNkey D4.1: Report on Knowledge-based exposure modelling framework depending on the accuracy and completeness of available data*. (p. 172). Bauhaus-Universität Weimar.
- Schwarz J., Maiwald H., Kaufmann C., Langhammer T., Beinersdorf S. (2019). Conceptual basics and tools to assess the multi hazard vulnerability of existing buildings. *Mauerwerk*, 23(4): 246–264. doi: 10.1002/dama.201910025
- Tertulliani A., Arcoraci L., Berardi M., Bernardini F., Camassi R., Castellano C., Del Mese S., Ercolani E., Graziani L., Leschiutta I., Rossi A., Vecchi M. (2011). An application of EMS98 in a medium-sized city: The case of L'Aquila (Central Italy) after the April 6, 2009 Mw 6.3 earthquake. *Bulletin of Earthquake Engineering*, 9(1): 67–80. doi: 10.1007/s10518-010-9188-4
- U.S.G.S. (2022). *M 6.3—3 km SE of Sassa, Italy*. USGS Earthquake Hazards Programs.
- Zuccaro G., Cacace F. (2015). Seismic vulnerability assessment based on typological characteristics. The first level procedure “SAVE.” *Soil Dynamics and Earthquake Engineering*, 69: 262–269. doi: 10.1016/j.soildyn.2014.11.003
- Zuccaro G., Perelli F.L., De Gregorio D., Cacace F. (2021). Empirical vulnerability curves for Italian masonry buildings: Evolution of vulnerability model from the DPM to curves as a function of acceleration. *Bulletin of Earthquake Engineering*, 19(8): 3077–3097. doi: 10.1007/s10518-020-00954-5