Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 44 (2023) 2036–2043

Structural Integrity Procedia

www.elsevier.com/locate/procedia

XIX ANIDIS Conference, Seismic Engineering in Italy

Investigation of architectural typological parameters influencing seismic vulnerability of masonry buildings in historical centres: the case of Puglia.

Chiara Tosto[a]*, Valeria Leggieri[a], Sergio Ruggieri[a], Giuseppina Uva[a]

[a]*Department DICATECh, Polytechnic University of Bari, Via Orabona, 4 – 70126, Italy*

Abstract

The paper presents a systematical study on the main architectural features characterizing existing buildings in historical centres and influencing their vulnerability under seismic actions. In particular, the first step of the work reports a macro-classification of historical centres on regional scale, obtained through a combination of multisource data with different degrees of detail, such as data from regional landscape plans, public datasets on web GIS and quick virtual inspections. After, all gathered data have been collected and processed in a proper georeferenced database, in order to analyze specific features and their geographic distribution, releasing a new taxonomy. Therefore, a regional abacus of building typologies has been defined through the main architectural and morpho-typological features influencing seismic vulnerability. The starting dataset has been compared by means of other available urban-scale data as those derived from CARTIS (structural-typological characterization for urban compartments), the procedure proposed in Italy for an extensive classification at national scale of recurring building typologies in municipalities. The result is a homogeneous macro-classification of historical centres enriched by typological information also finalized to estimate seismic vulnerability in a given area. The above procedure has been applied on the case study of Puglia region, showing a GIS tool reporting the classification for Apulian historical centres and the resulting abacus for the recurring building typologies.

Keywords: seismic vulnerability, regional-scale, historic centres, macro-classification, building typology, taxonomy

* Corresponding author. Tel.: +39 0805963832
E-mail address: chiara.tosto@poliba.it

10.1016/j.prostr.2023.01.260

1. Introduction

Masonry buildings in historical centres are the expression of collective memory and cultural values, in terms of architecture, typological features and traditional constructive techniques. For this reason, there is an important interest in their conservation and preservation, being one of the most seismic vulnerable elements in the Italian built heritage. As a matter of fact, the Italian Ministry of Culture released the "Guidelines on Cultural Heritage" (2010) to provide suitable methodologies for seismic risk evaluation of the cultural and historical heritage at different scales of analysis, starting from the territorial scale down to the building scale. Several approaches have been developed for the seismic vulnerability assessment of the historical building stock, employing different types of data sources with different resolution techniques, as shown by different authors, e.g., Casolo et al. (2000), Ramos and Lourenço (2004), Mallardo et al. (2008), Maio et al. (2016), Marra et al. (2021), Sferrazza Papa et al (2021), Casolo (2021).

Most of these studies, have a common approach that is based on the definition of building categories (like sufficiently representative of the building stock in an area under investigation) used for grouping sets of buildings with same typological and structural characteristics and, likely with similar seismic behavior. Generally, building macro-classification procedures are based on various taxonomies, as the ones by GEM taxonomy of Brzev et al. (2013), Lagomarsino and Cattari (2014), Pittore et al. (2018), Greco et al. (2020) and Silva et al. (2022), which are elaborated considering common recurrent morpho-typological features of buildings in a given area. In the same way, it is possible to define a suitable taxonomy able to represent homogeneous historical centres typologies, taking into account specific morphological and typological features of the urban fabric, as proposed in the form named "Historical Centres Form", released within the project by Italian DPC and GNDT (1999) , which as the aim to collect data about morphological and vulnerability features of historical centres.

Such an approach must be based on a preliminary process of extensive data collection to achieve a proper knowledge framework and to perform vulnerability assessment obtaining results with an acceptable reliability. To this aim, it is possible to extrapolate information exploiting freely available databases, quick investigations and rapid data collection form procedures as CARTIS by Zuccaro et al. (2015) employed in recent works as Formisano et al (2021), GNDT form by Benedetti and Petrini (1984); AEDES form by Baggio et al. (2007); ANTAEUS by Uva et al. (2014), Uva et al. (2019). The huge amount of data and the extension of the territory object of analysis require a suitable IT tool able to organize and process big georeferenced datasets. With this aim, the use of Geographic Information Systems (GIS) is becoming very widespread in the risk assessment field, as shown in several applications by Ferreira et al. (2013), Basaglia et al. (2016), Leggieri et al (2022), and Chieffo et al (2022) for historical centres analysis, allowing the management of multiple information layers, the implementation of different types of assessment procedures and the visualization of the results through thematic maps with regard to wide territorial areas.

In this broad framework, this work proposed a methodology to rapidly derive fundamental information for the implementation of simplified seismic vulnerability assessment methods for masonry building stock in the historical centres. A new taxonomy for historical centres has been developed, by analyzing the most recurrent morphological features of the urban fabrics within a region. After, by managing data characterizing the most spread architectural and structural typological features of masonry buildings, a regional abacus of masonry building typologies has been defined. Finally, by exploiting the correspondence with the available CARTIS catalogue of masonry building classes and homogeneous urban compartments for the region, the building typologies of the regional abacus have been associated to the historical centre classes. In this way, it is possible to identify some simple rules of correspondence between the morphology of historical centres and the nature of the masonry building typologies, in order to rapidly derive the information necessary for a seismic vulnerability assessment.

The methodology has been applied to the case study of Puglia region, Italy, elaborating the classification for Apulian historical centres and the abacus of the masonry building typologies. All results provided by the application of the proposed methodology are shown through thematic maps by using a GIS tool.

2. Methodology

2.1. Taxonomy definition for the historical centres at regional scale.

The first step consists in the definition of an original taxonomy for the historical centres, in which their recurrent morpho-typological features at regional scale are investigated using multiple information sources. The aim is to identify a minimum set of representative parameters with related attributes able to fully describe an ancient nucleus.

In this phase, the starting dataset is represented by the georeferenced database of the Italian census, provided by ISTAT (2011) in a digital format and directly implementable in GIS environment. The dataset is composed by vectorial/spatial files in which municipal areas are represented as polygons with related attributes.

Table 1. Parameters for an original taxonomy of historical centres.

Parameter	Description	Source	Attributes	Aggregated attributes
P_1	Foundation period	Regional Landscape Plan, historical studies	1. Ancient in continuity with Roma Age centre (4^{th} cent BC – 9^{th} cent. AD) 2. Middle Age foundation centre with preexisting Ancient and Roman settlement traces (10^{th} cent. – 16^{th} cent.) 3. Middle Age foundation centre with preexisting Roman settlement traces (10^{th} cent. – 16^{th} cent.) 4. Pre-Roman abandoned and refounded in Middle Age centre (10^{th} cent. – 16^{th} cent.) 5. Middle Age foundation centre (10^{th} cent. – 16^{th} cent.) 6. Modern foundation centre (17^{th} cent. – 19^{th} cent.) 7. Contemporary foundation centre (after 19^{th} cent.)	1. Ancient foundation centre (4^{th} cent BC – 9^{th} cent. AD) 2. Medieval foundation centre (10^{th} cent. – 16^{th} cent.) 3. Modern foundation centre (17^{th} cent. – 19^{th} cent.) 4. Contemporary foundation centre (after 19^{th})
P_2	Nucleus shape	"Historical Centres Form", Caniggia and Maffei (1979), historical studies	A. Centralized B. Middle Age maze C. Concentric D. Radial E. In-boundaries development F. Winding G. Linear H. Parallel development I. Open J. Multiple cores	1. Centralized 2. Linear 3. Open
P_3	Urban block shape	Direct measurements	1. Regular 2. Not regular	1. Regular 2. Not regular
P_4	Urban block dimension	Direct measurements	1. Small (side < 50m) 2. Medium (50m < side < 100m) 3. Large (side > 100m)	1. Small (side < 50m) 2. Medium (50m < side < 100m) 3. Large (side > 100m)
Classes of Taxonomy			**420**	**72**

As a result of a preliminary analysis, four fundamental parameters (with related attributes describing historical and morphological characteristics) have been identified: (a) foundation period; (b) nucleus shape; (c) urban block shape; (d) urban block dimensions. The parameters, described in detail in Table 1, have been implemented in GIS environment. Using the values of the above parameters, a simple but effective taxonomy has been proposed. In particular, historical centres can be described by a combination of a specific value for each of the identified parameters. All combinations amount to 420, which represent possible classes of ancient nucleuses.

Hereafter, similar attributes of some parameters can be aggregated to decrease significantly the number of classes (e.g., similar nucleus shapes can be joined). In this way, the combinations are reduced from 420 to 72, as shown in Table 1, obtaining a more synthetic taxonomy but still representative of all the historical centres.

2.2. Regional abacus of masonry building typologies

The following step regards the definition of an abacus of masonry building typologies, as representative of typical masonry structures within the historical centres and defining main recurrent architectural and typological features. The bases of the theory for identifying architectural buildings typologies are well illustrated in Caniggia and Maffei (1979). The identification of recurring building typologies, focusing on ordinary masonry buildings in a specific geographic area, cannot ignore local existing typological studies and professional experiences on the territory. To this aim, the information by Caniggia and Maffei (1979) should be properly enriched by rapid inspection campaigns to detect quantitative or qualitative recurrent architectural and typological characteristics that mainly influence the seismic vulnerability. As a rule of thumb, it is suggested to opt for freely web services, e.g., Google Street View. In Table 2 is shown the information on the architectural building typologies that compose an overall abacus, which is representative of the whole masonry building stock at regional scale. This tool can be used for employing typological-mechanical based seismic assessment methods.

Table 2. Parameters for each typology of the abacus of building typologies.

Parameter	Description	Description	Information
P_1	Geometry	Main architectural parameter for the acknowledgment of abacus typologies	Structural unit global dimension (m), openings typology and position, type of horizontal structures
P_2	Number of storeys	Storeys above ground; every more storey split the typology	(n.) 1, 2, 3 or more
P_3	Masonry characteristics	Masonry type and average compressive strength	Italian Building Code (N/mmq)
P_4	Wall thickness	In the same typology there could be combination of value for different panels	min – max (m)
P_5	Façade's openings	Percentage of openings separately for the ground floor and the upper ones	% (mq) of the façade's surface

2.3. Match between the taxonomy of historical centres and the abacus of building typologies.

The third step of the proposed framework aims to establish a relation between the building typologies composing the abacus and the historical centre classes defined through the previously shown taxonomy. This operation has been carried out using the CARTIS database, which provides detailed information about recurrent building typologies within homogeneous urban compartments of a municipality, according to Zuccaro et al. (2015). The correspondence between the homogeneous urban compartment of the ancient nucleus and the related CARTIS building typology for a municipality already investigated is the key information to develop the connection between the abacus of building typologies and the historical centres macro classes.

Firstly, as illustrated in Figure 1, it is possible to associate the abacus building typologies to the CARTIS masonry building classes by matching the related information: the comparison is guided by the number of storeys and the ground surface of the two databases. However, it is frequent that more than one abacus building typologies can be associated to one CARTIS typology, and this can be due to a not exact correspondence between analogous parameters, such as the number of storeys.

Then, the association is finalized by assuming the same abacus typologies related to a CARTIS municipality to all the other municipalities belonging to the same macro class of historical centres expressed by the released taxonomy, as schematically shown in Figure 1.

In the end, the connection between the two databases allows to reach several goals: (i) a quick association of a percentage of the abacus of building typologies to the historical centres thanks to a defined taxonomy; (ii) definition of parameters, grouped in the abacus of recurring building typologies, useful for seismic vulnerability assessment at regional scale.

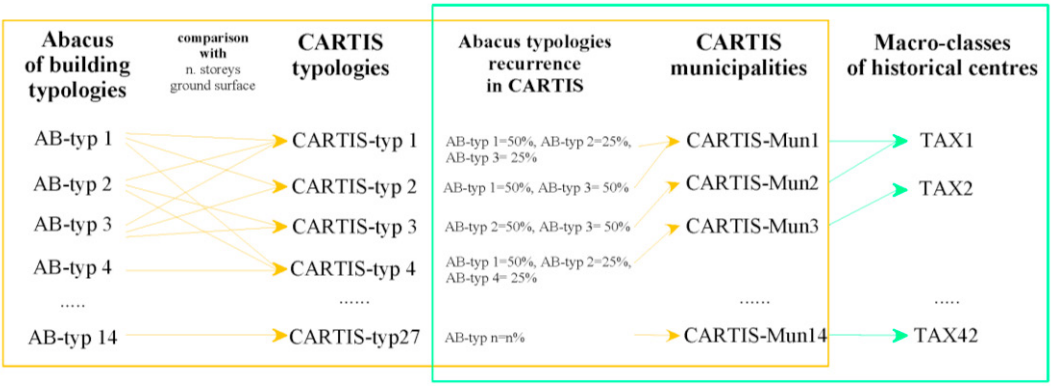

Fig. 1. Framework of the proposed methodology: in yellow, the first association; in green, the second association.

3. The case study of Puglia Region

3.1. Macro-classification of historical centres in Puglia Region

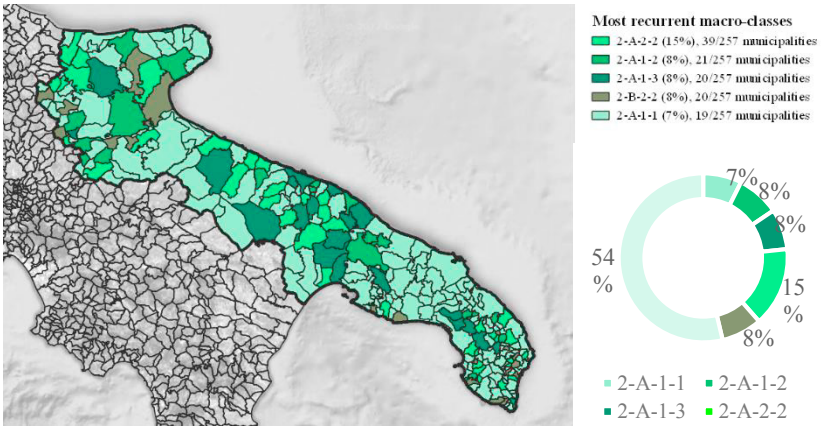

Fig. 2. Most recurrent macro-classes of historical centres and their percentage on the totality of the municipality of Puglia.

The proposed procedure has been applied on the case study of the Puglia region, which includes 257 municipalities, as provided by the last ISTAT online available census data (2011). The region is divided in 11 homogeneous sub-regional areas, under an environmental, morphological and historical point of view, as from the Regional Landscape Plan of Regione Puglia (2015).

After a first classification of historical centres of Puglia region, based on the proposed taxonomy, it is initially possible to observe on the occurrence in the territory of 97 macro-classes on the total of 420 (as reported in Table 1). Then, with the aggregation of similar attributes per parameter 42 existing macro-classes are observed on a total of 72 possible ones for Puglia Region. In Figure 2 is shows that 5 of them are representative of almost the 50% of the total number of municipalities.

Based on the released taxonomy, it is possible to highlight some aspects. The majority of the municipalities of (74%) was founded in the Middle Age period (from the 10th century to the 16th century), while a considerable number (14%), was founded in Ancient Period (up to the 9th century). Most of the nucleus's shape is defined as centralized

for the 61% of the municipalities, but the 28% show a linear development. There is not any difference between the parameters P_3 and P_4 about tissue shape and tissue dimension of historical centres after the aggregation process.

3.2. Abacus of building typologies in Puglia Region

In the investigation at urban scale, the recurring characteristics of the ordinary masonry buildings belonging to the historical centres have been identified. In particular, such characteristics have been collected varying some of them within likely ranges of values that allow each building typology to be representative of the whole asset. Moreover, additional architectural studies (Strappa, (2003), Cotecchia et al., (1993)) allowed to enhance the different building typologies collected in an abacus, as shown in Figure 3.

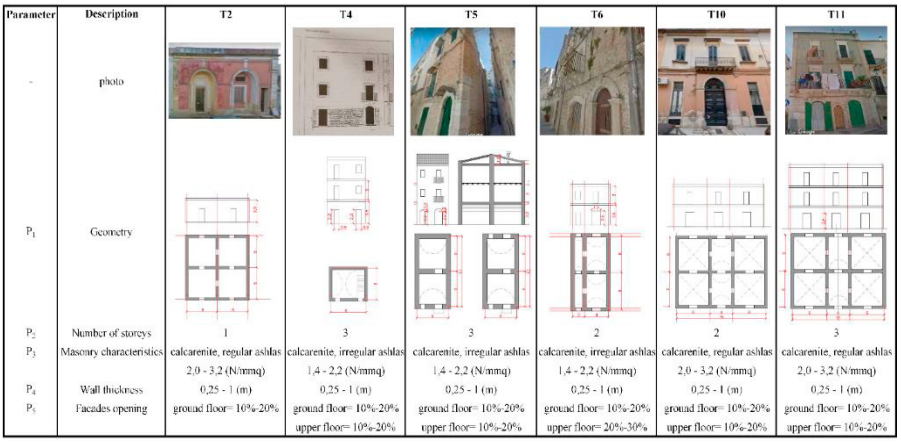

Fig. 3. Extract of the abacus of building typologies for Puglia Region.

More in detail, the residential units are identified by an association of a cellular-units with generally squared regular dimension, being representative for the first parameter. Different combinations of cells, usually 6 x 6 m, 4 x 6 m or 2 x 6 m, define several building typologies. The other geometric properties describe the architectural features of the "*casa a schiera*" configuration and its evolution in the "*casa in linea*", according to the variation of the cell units.

As previously mentioned, the number of storeys, as second parameter, is a distinctive feature for the abacus and it occurs for different typologies with same parameters except for the number of floors have been identified. In the abacus, buildings with more than three storeys are included in the typology with three floors. Moreover, a common element for all the considered cases is the constructive system of the masonry walls, as third parameter. Using the values proposed in the Italian Building Code (2018), it is possible to associate to each building typology a range of values for the mechanical parameters, in order to identify the masonry layout of irregular and regular calcarenite stones. As well, the fourth parameter is related to the wall thickness, expressed through a range of value in meters, from 0,25 m to 1 m (also combined for different panels in the same typology). The last parameter is the panel's interruption due to openings: it is characterized by a range of percentages that goes from a minimum of 10% of the façade surface to a maximum of 30% (separately for the first and the higher floors).

In the end, the released abacus is composed by 14 building typologies, where each typology is representative of the Apulian ordinary masonry building in historical centres.

3.3. Connection between abacus and macro-classification.

Puglia Region is compiling the CARTIS database with the RELUIS project up to 2021, having now available data for 14 municipalities in the region.

For the present work, only masonry building typologies belonging to the CARTIS compartments associated to the most ancient ones are considered, for which geographic information is available. In the CARTIS database of Puglia,

there are 27 building typologies as representative to the masonry building typologies in the identified ancient nucleuses.

The association between CARTIS database and the abacus derives from specific rules based on the comparison between the ranges of values assigned to the common parameters. The first comparison is performed between the ground area of the abacus and the relative values expressed in CARTIS. The second association is carried out between the number of storeys, associating each CARTIS value with the abacus ones. This step often allows to identify more than one abacus typology that will be associated to the CARTIS typology. An example of this association is provided in Table 3 for an extract of CARTIS typologies.

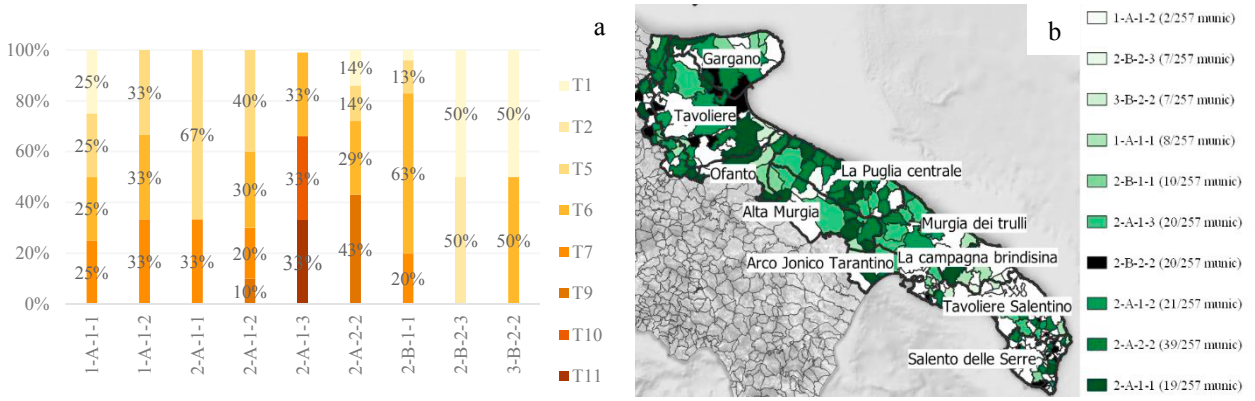

Fig. 4 (a) Connection between abacus typologies and macro-classes of historical centres according to CARTIS database, (b) Municipality of Puglia Region, for each sub-regional area, with complete (in green) and not complete (in white) matching abacus-macroclasses.

Applying the above rules for the case at hand, a first goal of the presented procedure is achieved: in Figure 4a are shown the abacus building typologies percentages for each associated macro-class for historical centres, representing for almost the 52% of the municipalities in Puglia with a complete association. In Figure 4b is shown the graphical outline of the obtained result. It comes out that, one of the most populated macro-classes of historical centres results out of the match, because there are no surveyed by CARTIS municipalities able to complete the association. The remaining municipalities without a complete association (in white) need further investigation with CARTIS form.

4. Conclusion

The present work provides a novel approach for a quick attribution of information at building typology scale of recurrent building typologies to a regional macro classification of historical centres. It takes in advantage the use of GIS tools for the overlapping and managing multi source information and produce synthetic graphic map as outcomes.

The municipalities under investigation are the total number for the Puglia Region taken in account, and they have been analyzed highlighting morphological and typological aspects flowing into an original taxonomy. Thanks to this first phase of the process, it has been possible to highlight some aspects of the historical centres among the region, as their prevalent foundation period in the Middle Age and their most frequent development in centralized nucleus shape. Hereafter, recurring architectural building typologies within the ancient nucleus have been identified by the investigation of a restrict number of parameters influencing of seismic vulnerability. The main building typologies as the *"casa a schiera"* and the *"casa in linea"* and their several variations compose the regional abacus.

The two data collection have been matched by using the available CARTIS database for the Puglia Region. Similar properties, as the number of storeys and the ground area, have been compared and associated from the building typology scale to the macro-classification of historical centres. In the end, it is possible to highlight percentage quantification of the detected typological information on the regional scale.

References

Baggio, C., Pinto, A.V., Taucer, F., 2007 Field Manual for post-earthquake damage and safety assessment and short term countermeasures (AeDES), JRC Scientific and Thechnical Reports, pp. 1–100.

Basaglia, A., Aprile, A., Spacone E., Pilla, F. 2018. Performance-based Seismic Risk Assessment of Urban Systems, International Journal of Architectural Heritage.

Benedetti, D., Petrini V., 1984. On the seismic vulnerability of masonry buildings: A method of evaluation, L'industria delle Costruzioni. pp. 66–74.

Brzev, S., Scawthorn, C., Charleson, A. W., Allen, L., Greene, M., Jaiswal, K., Silva, V. 2013. GEM building taxonomy (Version 2.0) (No. 2013-02). GEM Foundation. Technical Report, pp. 1-188.

Caniggia, G., Maffei, G. L. 1979. Composizione architettonica e tipologia edilizia 1. Lettura dell'edilizia di base. Venezia: Marsilio.

Casolo, S., Neumair, S., Parisi, M. A., & Petrini, V. 2000. Analysis of seismic damage patterns in old masonry church facades. Earthquake Spectra, 16(4), 757-773.

Casolo, S. 2021. Macroscale modelling of the orthotropic shear damage in the dynamics of masonry towers by RBSM. Engineering Failure Analysis, 130.

Chieffo, N., Formisano, A., Landolfo, R., Milani G. 2022. A vulnerability index based-approach for the historical centre of the city of Latronico (Potenza, Southern Italy). Engineering Failure Analysis, 136, 106207.

Cotecchia V., Farenga T., Loiacono P. 1993. Le Pietre da Costruzione ed il territorio, in: *"Le pietre da costruzione: il tufo calcareo e la pietra leccese"* Atti del Convegno Internazionale, Bari 26-28 maggio 1993, pp 15-32 (in italian).

Dipartimento Protezione Civile e GNDT. 1999. Progetto interregionale per la mitigazione del rischio sismico relativo alle emergenze e a carattere monumentale ed ambientale nei Comuni ricadenti in tutto o in parte all'interno dei parchi naturali dell'Italia meridionale. (in italian).

Ferreira, T. M., R. Vicente, J. M. Da Silva, H. Varum, and A. Costa. 2013. Seismic vulnerability assessment of historical urban centres: Case study of the old city centre in Seixal, Portugal. Bulletin of Earthquake Engineering 11 (5):1753–73.

Formisano, A., Chieffo, N., Clementi F., Mosoarca, M. 2021. Influence of Local Site Effects on the Typological Fragility Curves for Class-Oriented Masonry Buildings in Aggregate Condition. The Open Civil Engineering Journal. 1874-1495/21

Greco, A., Lombardo, G., Pantò, B., Famà, A. 2020. Seismic vulnerability of historical masonry aggregate buildings in oriental Sicily. International Journal of Architectural Heritage, 14(4), 517-540.

Lagomarsino, S., Cattari,S., 2014, Fragility Functions of Masonry Buildings, in *"SYNER.G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk"* Springer, Dordrecht., pp. 111-156.

Leggieri, V., Mastrodonato, G., Uva, G. 2022 GIS Multisource Data for the Seismic Vulnerability Assessment of Buildings at the Urban Scale. Buildings, 2022, 12, 523.

Maio, R., T. M. Ferreira, R. Vicente, and J. Estêvão. 2016. Seismic vulnerability assessment of historical urban centres: Case study of the old city centre of Faro, Portugal. Journal of Risk Research 19 (5):551–80.

Mallardo, V., R. Malvezzi, E. Milani, and G. Milani. 2008. Seismic vulnerability of historical masonry buildings: A case study in Ferrara. Engineering Structures 30: 2223–2241.

Marra, A., Sabino, A., Bartolomucci, C., Trizio, I., Mannella, A., & Fabbrocino, G. 2021. On a rational and interdisciplinary framework for the safety and conservation of historical centres in Abruzzo Region. International Journal of Architectural Heritage, 15(4), 608-626.

Ministero dei Beni e delle Attività Culturali, Linee Guida per la valutazione e riduzione del rischio sismico del patrimonio culturale, 2010.

Ministero delle Infrastrutture e dei Trasporti. 2018. Aggiornamento delle "Norme tecniche per le costruzioni", 2018, (in italian).

Pittore, M., Haas, M., Megalooikonomou, K. G. 2018. Risk-oriented, bottom-up modeling of building portfolios with faceted taxonomies. Frontiers in Built Environment, 4, 41.

Ramos, L. F., and P. B. Lourenço. 2004. Modeling and vulnerability of historical city centres in seismic areas: A case study in Lisbon. Engineering Structures 26 (9):1295–310.

Regione Puglia 2015. Piano Paesaggistico Territoriale Regionale (PPTR), Approvato con Deliberazione della Giunta Regionale n. 176 del 16/02/2015, aggiornato al 2021 (in italian).

Sferrazza Papa, G., Tateo, V., Parisi, M. A., & Casolo, S. (2021). Seismic response of a masonry church in central italy: The role of interventions on the roof. Bulletin of Earthquake Engineering, 19(2), 1151-1179.

Silva, V., Brzev, S., Scawthorn, C., Yepes, C., Dabbeek. J., Crowley, H., 2022, A Building Classification System for Multi-hazard Risk Assessment, International Journal of Disaster Risk Science.

Strappa, G., Ieva, M., Dimatteo, M. A. 2003. La città come organismo. Lettura di Trani alle diverse scale. Dipartimento di Scienze dell'Ingegneria Civile e dell'Architettura - Politecnico di Bari, collana di saggi e monografie. Mario Adda Editore (in italian).

Uva, G., Sanjust, C.A., Casolo, S., Mezzina, M. 2014. ANTAEUS Project for the Regional Vulnerability Assessment of the Current Building Stock in Historical Centers, International Journal of Architectural Heritage 10(1) (2016), pp. 20–43.

Uva, G., Sangiorgio, V., Ciampoli, P.L., Leggieri, V., Ruggieri, S. 2019. A novel rapid survey form for the vulnerability assessment of existing building stock based on the 'index building' approach. Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics 2019, 8914063, 976–981.

Zuccaro, G., Dolce, M., De Gregorio, D., Speranza, E., Moroni, C. 2015. La Scheda Cartis Per La Caratterizzazione Tipologico - Strutturale Dei Comparti Urbani Costituiti Da Edifici Ordinari. Valutazione dell'esposizione in analisi di rischio sismico, 34 Convegno Nazionale GNGTS, Trieste, (2015), pp. 281–287 (in italian).