A strategic-multidisciplinary approach to reduce the seismic risk. Ongoing activities within the ADRISEISMIC project.

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Abstract. *Many active faults make the Adriatic-Ionian area one of the most prone to seismic events in the entire European continent. Earthquakes, which are often disastrous, have strongly affected the building practice and the culture of the countries involved, inspiring specific regulations and prescriptions that have followed over the years. However, despite the progress, the historic centres are still characterised by a high vulnerability, while the acquired knowledge and experience often remain confined within national borders.*
Within this framework, a specific study has been conducted as part of the ADRISEISMIC project, funded by the Interreg Adrion programme, to address seismic vulnerability through a multidisciplinary approach. Starting from the surveys carried out in the Countries involved in the project (i.e., Italy, Serbia, Albania, Greece, Slovenia and Croatia), the most common construction techniques, numerical assessment methods, and good practices for the reduction of seismic risk at different scales were collected and catalogued. An expeditious method to assess the seismic behaviour of reinforced concrete and masonry buildings has also been developed. The elaborated protocol is in its validation phase and will be shown referring to the case study of Piazza Puntoni in Bologna. These investigations are the basis for developing guidelines and harmonised procedures to integrate the assessment of seismic risk in the urban planning tools. Investigating seismic vulnerability at territorial scale can support the identification of urban regeneration strategies and, consequently, the prioritization of seismic risk reduction intervention in areas subjected to a higher risk.

Introduction

Seismic risk has always been a paramount issue for Italy and the south-eastern European area. Indeed, the specific morphological configuration of the area makes it prone to earthquakes of considerable magnitude, often with catastrophic consequences for man-made areas. Disaster-hit countries have traditionally faced the consequences of seismic risk without a shared approach, developing their own solutions to the problem. There have been many studies on building vulnerability assessment over the years, Calderoni (2016) and Moufid Kassem (2020) being some of the most recent examples. Interesting approaches on the subject are also illustrated by Clavi (2006) and Giuffrè (1996), the latter offering a specific view on historic centres. Only in recent years, with the increase in international collaborations, and thanks to the European funded programmes, the need to create common criteria for intervention has started to be satisfied.

Moreover, historic centres, squares and their surrounding buildings are conceived as symbol of local identity and socio-economic cores for the Adriatic-Ionian area settlements. At present, the seismic vulnerability of historic areas is mainly addressed at building level (Bernardini e Ferreira 2021), but sectorial studies are often not able to address the interrelated consequences of earthquakes on complex socio-economic systems like cities are. The diagnosis of seismic risk at urban level is considered of great importance to bridge this gap even though its potential is underestimated (Marzani et al., forthcoming). A large-scale assessment of seismic risk takes into consideration the relationships between buildings and public spaces, and it is capable of orienting planning strategies for the regeneration of the entire city (Lorenzo, 2017).

The ADRISEISMIC project fits into this context and, through a multidisciplinary approach, it aims to develop a common protocol for seismic risk reduction in the project partner countries. The work presented here, briefly goes over the main points of the ADRISEISMIC project developed so far, describing its general context and structure. A special section is then dedicated to the work carried out on the Italian Pilot Action of Piazza Puntoni, the survey phases, the data acquisition phases, and the results obtained through the application of the method. In this way, a general knowledge of the entire project is given, both from a procedural and operational point of view. The last chapter describes the first considerations on the evaluation protocol, obtained from its application to the Italian Pilot Action.

The ADRISEISMIC Project

ADRISEISMIC is an EU project funded under the Interreg Adrion Programme, which is specifically devoted to address common challenges through territorial cooperation. The main objective of the project is to exchange and systematise knowledge and practices to counter seismic vulnerability in historic urban areas and squares. To this aim, eight partners from six different countries (i.e., Italy, Croatia, Slovenia, Greece, Albania and Serbia) are involved. The participants have different backgrounds in terms of expertise and the territorial level they represent.

Two different Italian partners are involved in the project, bringing specific and complementary competences: the Alma Mater Studiorum - University of Bologna (UNIBO) – Department of Architecture and the Institute for Vocational Training of Construction Workers in the province of Bologna (I.I.P.L.E.). On the one hand, UNIBO is responsible for the overall project coordination and brings theoretical support to the activities concerning the analyses of seismic vulnerability, the policy framework and urban planning regulations and strategies; on the other hand, I.I.P.L.E. is responsible to support the creation of new training packages increasing the impact of the project and fostering the creation and dissemination of new knowledge for specific target

groups.
The City of Kaštela in Croatia and the Municipality of Gjirokaster in Albania are the two local public authority involved as project partners. Both settlements have a strong seismic exposure and a rich architectural and cultural heritage to preserve. This condition makes the areas very sensitive to the issues addressed in the project and, consequently, suitable for both the implementation of harmonised regulations and the testing of the techniques introduced by the project. Being local government institutions, they have the authority to implement their policy framework endorsing ADRISEISMIC project results and to develop innovative strategies for the conservation of the built heritage.
Regional development agency Bačka (Serbia) is a body founded by local municipalities to develop coordinated actions for the socio-economic improvement of the region. Similar to the Region of Crete (Greece), their participation is aimed, on the one hand, to test new planning tools and programmes acquiring detailed knowledge to be transferred to the local actors involved, and on the other hand, to develop specific activities with the regional and local administrative bodies for the implementation of innovative regulations.
The remaining two partners are the Slovenian National Building and Civil Engineering Institute and the University of Crete. The two research institutes directly support the development of the project activities, providing expertise respectively in the structural field and in training the volunteers to respond to the emergency phase.
The project identifies three specific objectives:
1) Harmonisation of technical norms and financing tools for seismic vulnerability reduction;
2) Enhancement of the competencies/skills on seismic vulnerability of all the professional figures involved in the construction process and in the management of the emergency phase;
3) Codification of effective diagnostic methods and intervention techniques for seismic retrofitting.
ADRISEISMIC project foresees two main outcomes: on the one hand the establishment of an international cooperation to jointly tackle seismic vulnerability; and on the other hand, regional/local action plans, aimed at embedding the shared methods for assessing seismic vulnerability of aggregates of buildings and other actions to increase resilience towards seismic vulnerability into the local and/or regional planning instruments.
The first series of activities dealt with the harmonisation of the tools and approaches adopted by the project partners in terms of standards, operations and economic-financial instruments. The collection and systematisation of the standards and incentives currently adopted in the various areas covered by the ADRISEISMIC project have been performed. This step led to a knowledge base of the current situation, highlighting the most advanced approaches and those most replicable to the various contexts. The results consist of a repository of good practices, intended as virtuous initiatives, documents and laws already in place in one of the countries involved in the project to be potentially replicated and transferred to other contexts. At the end of the project, six roadmaps (i.e., one for each country) will be drafted to explore the pathways that each country intends to develop to tackle seismic risk and increasing resilience working on the improvement of their policy and planning framework.
In addition, a lack of specific skills and high-qualified actors to properly deal with the seismic hazard and its effects was detected. Therefore, the need to enhance competences of all the actors involved in the seismic retrofitting process at local level has been envisaged. Based on the analysis of the available training methods regarding seismic improvement interventions in the ADRISEISMIC countries, three specific training packages (i.e., addressing practitioners, civil servants, and workers) have been developed. An additional toolkit designed for volunteers is

planned and structured with both theoretical modules and hands-on activities. All the courses are available on the project Moodle platform.
Besides the analysis and improvements of the regulatory framework and the training offer, the project focuses on the development of an expeditious method for the assessment of seismic risk of the existing heritage. Focusing on buildings facing historic squares, therefore characterised by a load-bearing structure in reinforced concrete and masonry, all available information was initially collected on the construction techniques, intervention techniques and assessment methods for each of the countries involved in the project. The survey carried out ensured a widespread knowledge of the state of the art, establishing the starting point for the subsequent activities.
Two different assessment protocols were implemented: the first concerns reinforced concrete buildings, the second masonry buildings. The two systems, although distinct, maintain almost identical characteristics in terms of the input and output provided by the system at the end of the data processing phase. This preserved the consistency and comparability necessary for the two systems to be used in parallel on the same urban areas.
The ADRISEISMIC method was therefore used in three areas set in three different countries (Pilot Actions). The aim was to test the method also from an operational point of view, having both the possibility of investigating possible strengths and weaknesses of the system, and the possibility of verifying its versatility by operating on areas with very different characteristics.

Italian Pilot Action: Piazza Puntoni

The Italian Pilot Action of Piazza Puntoni, located in the city of Bologna, was the first to be fully developed. The investigations and activities carried out served as a reference for the other pilot actions in the project (located in Kaštela in Croatia, and Rethymno in Greece). The three areas were chosen following the objectives and themes investigated by the project. Priority was therefore given to buildings facing urban squares, preferably with a historical connotation, and characterised by constructions with a reinforced concrete or load-bearing masonry structure.
The investigated Bolognese area is located in the University area, within the medieval walls that traditionally characterise the oldest part of the urban centre. Although the square is located in the most historical part of the city, it is of recent construction. The public space is the product of demolition works that took place in the 1930s with the aim of redesigning the entire district and making it the hub of university life in the city. Due to these transformations, it has a very peculiar shape (a sort of right-angled triangle) and is bordered on all sides by driveways. Its conformation makes it more a transit point than a meeting place, as squares are often understood. However, it is precisely its particular genesis that has made it the ideal place to study: it is in fact surrounded both by historic masonry buildings, conceived with traditional techniques and used for both public (University) and private (homes and shops) functions; and by relatively recent buildings, characterised by reinforced concrete structures and Twentieth-century masonry ones.
Specifically, it is possible to group the buildings into six groups with similar characteristics: the University library, the Department of Economics, the National Gallery of Bologna and Fine Arts Academy, the University student house and canteen, a sundial building and ancient residential buildings.
The University Library is also the seat of the University of Bologna. It extends planimetrically over several blocks and is characterised by a very articulated layout. The original layout, to whom numerous extensions and modifications have been made over the centuries, dates back to

1549; it was erected at the wishes of Cardinal Giovanni Poggi, who wanted it as his personal residence. It became the property of the University in 1803, after also serving as the Academy of Sciences. Structurally, it presents very diversified configurations. The portion facing Piazza Puntoni, that is the subject of the project, is characterised by load-bearing masonry walls in the elevation and floors made of wood or by arches and vaults.

The Department of Economics is one of the buildings conceived together with the new layout of the square, thus dating back to the second half of the 1920s. Although aesthetically congruent with the adjacent Palazzo Poggi, the construction techniques are different. The vertical load-bearing elements are made of masonry with higher characteristics, and the floors in the classrooms are made of reinforced concrete.

The building hosting the University student house and the canteen is the most recent among the ones facing the square. Its inauguration took place on the 25th November 1954, after one and a half years of construction work. Its distinctive form was imposed by the configuration of the plot, located in a historic district and surrounded by many existing buildings. The external façades seek a dialogue with the surrounding context, proposing the typical elements of the city's tradition, such as the portico on the ground floor, the exposed masonry façades and the regular rhythm of the openings.

However, the external configuration conceals an internal structure composed of reinforced concrete beams and columns, designed to support large spans (over eight metres). The flat roof, later elevated by a metal frame, is another element of discontinuity with the neighbouring buildings.

The National Gallery of Bologna and Fine Arts Academy is the building with the most articulated history. Over the years it changed function several times and, as a consequence, the original layout has been modified each time. In a planimetrically barycentric position, the former Santo Ignazio church is (1728-1735), while the portion parallel to Via de Rolandis (Collamarini area) dates back to the 1960s and has a reinforced concrete structure. The complex currently houses the paintings gallery, offices of the Superintendency, the Academy of Fine Arts and an art school.

The sundial building is located in the immediate neighbourhood of the intersection of Via de Rolandis and Via Zamboni, and therefore has a triangular planimetric configuration. Built in the second half of the 1930s, it presents peculiar and heterogeneous characteristics: the ground floor is partially made of coloums, while the rest of the structure is made of load-bearing masonry. The floors are realised either by steel beams or, on the upper floors, by precast concrete elements. Currently, the ground floor is dedicated to commercial activities, while the upper floors are dedicated to private residences.

The last buildings investigated, collected here in a group for convenience, are the ancient residential buildings. The units, hypothetically constructed with similar techniques and materials (it was not possible to carry out in-depth investigations), can be defined as a structural aggregate. Their conformation, created by successive extensions, makes it very difficult to identify defined structural units. Installations of this type are very common in all ancient historic centres and are often the most vulnerable parts of the city. Not only because of their intrinsic criticality, but also because of the difficulty in implementing coherent and shared structural measures. Currently, the ground floor is dedicated to commercial activities, while the upper floors are private residences. Structurally, they are characterised by load-bearing masonry, while the floors are either made of vaults or wooden elements.

The application of the protocol and the consequent obtaining of results required a preparatory and preliminary investigation phase. Initially, all possible material on the buildings was searched,

and archives and cadastral databases were consulted. For the buildings of the University of Bologna, access was gained to the executive drawings (when they existed) and also to the plans deposited with the municipal authorities. This made it possible to arrive at a historical and morphological reconstruction of the entire area.
The material served both as a cognitive basis and to hypothesise the characteristic construction techniques of those buildings for which no certain data was available. In this regard, the recognition work carried out in the first months of the project, when an attempt was made to catalogue all the techniques typical of the areas covered by the ADRISEISMIC project (Predari, 2022), was of fundamental importance.
At the end of the archival research, it was possible to define for each building: the historical analysis, the planimetric configuration and typical plans, the hypothesis of the structural system and the construction solutions.
Parallel to the documentary research work, site surveys were carried out, aimed at the dimensional acquisition of all the elevations facing the square. It was decided to operate both using a photogrammetric analysis and a laser scanner (or lidar) analysis. This made it possible to determine which of the two methods was the best one for the intended application of the project.
The first survey was carried out by means of terrestrial photogrammetry: the operator, using reflex cameras, at the beginning covered the entire surface of each elevation, then processed the photographs using software and generated the point cloud. The second campaign was carried out using a similar process: initially, 23 laser scanner points (stations) were set up to acquire the entire square; then the data was processed through software. The two analyses allowed, in both cases, a faithful reconstruction of the study area, capturing details more accurate than a structural assessment requires. The difference between the methods were evaluated considering accuracy, data processing time, personnel and instrument costs.
The accuracy of laser scanner is higher, about one centimetre compared to 3-5 cm for photogrammetric analysis (in any case more than sufficient for the purpose). The processing time is shorter for the laser scanner: the survey took one morning for field analysis and about three hours for processing, while the photogrammetric analysis took two days for filming and about five hours for processing for each building. The cost of personnel, understood as specific training, can be evaluated as equivalent for the two methods. Photogrammetry, on the other hand, is better from a cost point of view: laser scanner is a specific instrument, therefore often not available for expeditious analysis, and implies very high purchase costs. Terrestrial photogrammetry, as mentioned, allows results to be obtained with any imaging instrument.
From the aims of the project, considering the need to contain costs and to allow its application to the widest possible audience, the adoption of photogrammetric analyses was deemed ideal since, although less accurate, they better meet the requirements sought.
Once the cognitive phase was completed (documentary research, field surveys and material processing), the ADRISEISMIC method was applied to all the buildings under study.
The method, whether applied to reinforced concrete or masonry buildings, provides some useful outputs to judge the seismic performance of a building. Specifically, seismic vulnerability, understood as the building's potentiality for damage, seismic risk and the most probable damage mechanism, is provided. In the case of the masonry method, it is also possible to obtain information on masonry quality (for this, the MQI method has been borrowed, Borri 2019).
The results are obtained by incorporating inputs derived from the surveys and research conducted into the two assessment protocols. Schematically, for reinforced concrete buildings,

the following are requested: designed use, floors above ground, irregularities in plan, irregularities in height, expected ductility, concrete strength, steel strength, column dimensions, transverse reinforcement (in columns), longitudinal reinforcement (in columns) and presence of large spans. For masonry structures, on the other hand, in addition to the data required by the MQI method (which for reasons of brevity will not be reported), it is necessary to define: designed use, floors above ground, irregularities in plan, irregularities in height, transversal wall distance, wall thickness, floor height, connections between structural elements, expected ductility, permanent floor loads, thrusts due to arches or vaults (floor level) and thrusts due to arches or vaults (roof level).
The data are necessary for the definition of seismic vulnerability, called "structural response index" in the method. Seismic risk is instead defined as follows:

$$S_h=I_v \cdot E \cdot H$$

Where:
S_h is the seismic risk;
I_v is the vulnerability index, i.e., the inverse of the index of structural response;
E is the exposure;
H is the seismic hazard;

Each of these parameters, has been defined using the European seismic standards (European Committee for Standardization, 1998) as the main reference and the Italian technical standards (Ministero delle infrastrutture e dei trasporti, 2018) where there are no specific international references. It is therefore clear that the hazard is identical for all the buildings investigated, since both the acceleration (0.167g) and the type of soil (type C, as in Eurocode 8) are the same.
All the results obtained for the buildings under study are shown below in tabular form:

Building	Index of structural response	Index of structural response category	Most probable collapse mechanism	Seismic risk	Seismic risk category
University library	0.28	II	Horizontal deflection	1.09	High
Department of economics	0.71	V	Vertical deflection	0.43	Low
University Student House and canteen	0.32	II	Soft storey mechanism, torsional effects, ductile column failure	0.91	High
National Gallery of Bologna and Fine Arts Academy	0.40	III	Simple masonry overturning	0.75	Medium
Sundial building	0.49	III	Vertical deflection	0.49	Medium
Ancient residential buildings	0.35	II	Cantonal Overturning	0.86	Medium

Table 1. *(Results obtained in the bologna pilot case)*

From the results, the buildings with the highest vulnerability are the University library and the University student house and canteen, having values of 0.28 and 0.32 (where zero is the highest vulnerability and 1 the best result). Similarly, having the same hazard and high exposure, they also show the highest seismic risk (high), while the Department of Economics, having been the subject of improvement works in the past decades, shows values of low seismic risk (0.71) and low risk (low). The categories (very high, high, medium, low and none) of seismic risk are associated with the respective numerical value, higher numerical values imply higher categories.

In general, the buildings facing the square, with the exception of one case, have a low seismic capacity and therefore a medium-high seismic risk.

Conclusions

The activities conducted within the ADRISEISMIC project are aimed at seismic risk reduction using a multidisciplinary and coordinated approach on a transnational scale. Therefore, in the course of the Project, two parallel systems for expeditious assessment of the seismic response of reinforced concrete and masonry buildings were defined (the ADRISEISMIC method). Once developed, the method was applied to three Pilot Actions, selected to offer the greatest possible variety in terms of construction techniques and construction periods. The specific case discussed above, namely the Piazza Puntoni area located in Bologna, was the first implementation of the method on real buildings.

The work carried out on the Pilot Actions allowed the first feedbacks from the assessment algorithm to be obtained, showing some criticalities (especially in terms of information acquisition) and some strengths. The method, both for reinforced concrete and masonry, was easy to use and very fast in returning the results (seismic vulnerability and seismic risk). In addition, the adoption of Eurocode 8 as the reference for input parameters and the decision to avoid specific national regulatory references can guarantee its widespread use, going beyond the national scale.

The most time-consuming part resulted to be the information acquisition. It is not always possible to obtain executive drawings, floor plans and elevations of all buildings, especially in the case of urban-scale applications. For this reason, possible survey methods were investigated, conducting campaigns on the area with both laser scanner and photogrammetry. It was found that, considering the framework, both surveys conducted offer excellent results in terms of accuracy. However, photogrammetry was found to be preferable due to the lower costs of the necessary equipment and consequently was found to be more accessible.

The duality between accuracy and required analysis time is typical of expeditious assessments, which is the reason to use the system consciously, having the possibility of introducing assumed data when necessary, reducing assessment time and, to some extent, the reliability of the results.

The analyses conducted so far through Pilot Actins have, thus, represented an initial application of the method on different national contexts, showing encouraging perspectives for a more widespread use on a larger scale. The method can be adopted to conduct seismic expeditious as assessment at urban level, fostering the integration of seismic vulnerability reduction strategies into urban planning discipline and tools. This will support policymakers in identifying priorities of intervention for different areas of the city in favour of urban regeneration practices towards safer cities and conscious investments of public financial resources.

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Illustrations and Tables

Figure 1. (The three pilot actions: Piazza Puntoni, Bologna; Platia Koroneou ke Periferiakos, Rethymno; Kaštel Sućurac, Kaštela © Google Maps)

Figure 2. (From left to right, first line: university library, department of economics, national gallery of Bologna and fine arts academy; second line: university student house and canteen, sundial building and ancient residential buildings © Predari)

Figure 3. (On the left the mesh generated by the photogrammetric survey, on the right the point cloud from the laser scanner survey © Stefanini)

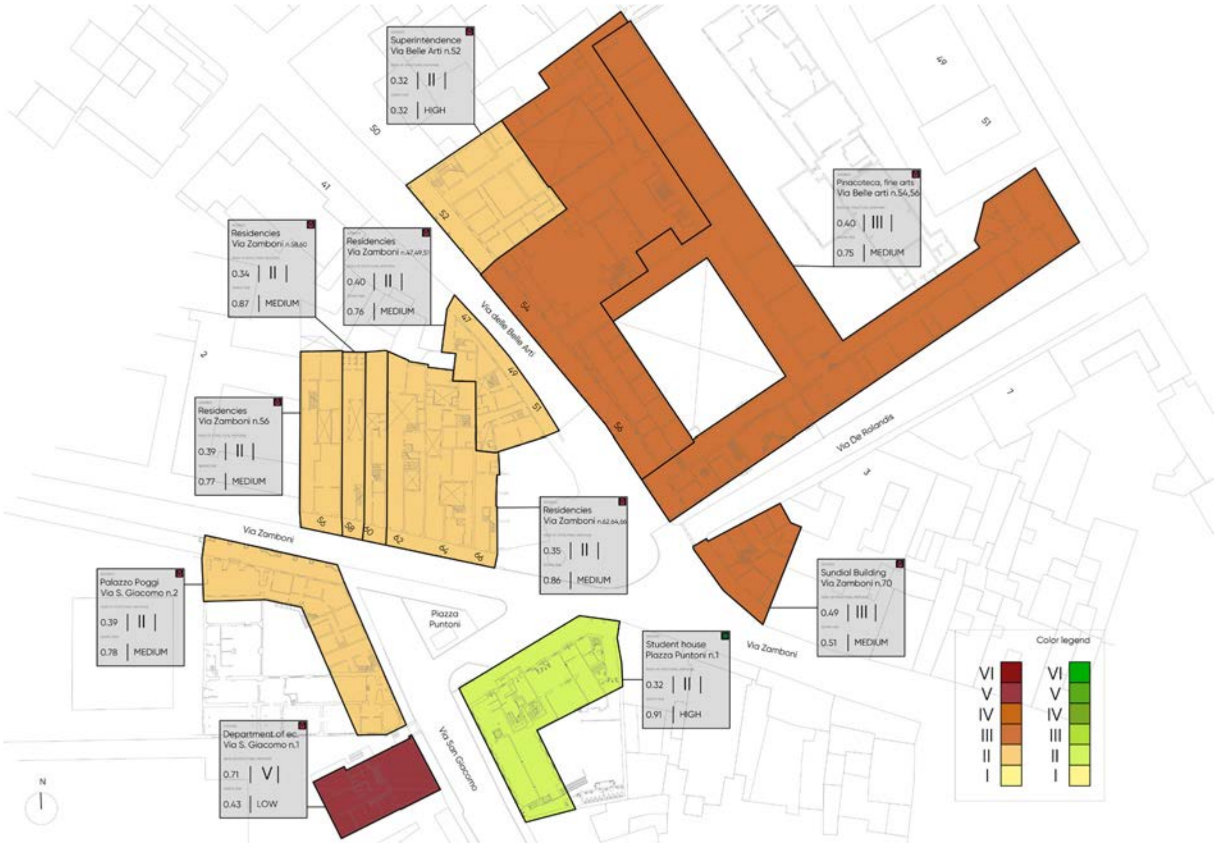

Figure 4. (Plan view Piazza Puntoni with the assignment of vulnerability and seismic risk classes © Stefanini)