

sous la direction de  
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## Villages et quartiers à risque d'abandon

*Stratégies pour la connaissance,  
la valorisation et la restauration*

TOME 1

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## VULNERABILITY OF HISTORICAL CENTRES: THE CASE OF CAMERINO (MARCHE REGION)

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Enrica Petrucci, Lucia Barchetta, Diana Lapucci  
Università degli Studi di Camerino-Italia

Depth of bedrock: it is evident that part of the northern sector of the arenaceous relief is characterized by very thick cover deposits, at places even higher than 10 mt.

The seismic activity that has always shaken the Italian territory and especially the latest events (earthquake in Central Italy 2016) - highlighted again the structural fragility of the historic centres, which are mostly made up of masonry buildings, often of poor quality, and characterized by typical and specific vulnerabilities that do not allow sufficient resistance to the seismic phenomenon. In particular, the small historical centres in the Marche region are mainly characterized by a “spontaneous” architecture, generally made up of poor materials. Moreover, these historic centres are located in internal areas with high seismic risk and have, consequently, a very high exposure linked to different factors and for this reason, it is extremely complex to characterize their vulnerability and predict their damage conditions. In recent years, the Marche region developed a susceptibility to seismic risk due to the intensification of earthquakes, with a frequency of events different from what can be estimated in probabilistic terms. The different local conditions have had a decisive influence on the damage to the historical-artistic heritage which, in many situations, reached the almost total collapse of the structure. In the present research, a methodology is applied for an assessment of the vulnerability of historic centres at an urban scale, analyzing, in particular, a case study (Camerino) to verify how some conditions (historical evolution, aggregation systems, construction techniques) and some factors (site amplifications, details locations, transformation level) affect its fragility.

**Keywords:** earthquake, vulnerability, historical centres, methodology.

### Introduction

In the methodological approach, an accurate survey of the damage caused by seismic events is expected and, in general, an assessment of the building clusters vulnerability; the information will be managed through a GIS system for the mapping of damage and vulnerability from which to potentially deduce the actions aimed at risk reduction and prevention. The assessment of the building vulnerability as part of an urban-scale seismic risk analysis is certainly one of the critical points for which the choice of the level of investigation is fundamental. For this reason, the existing procedures for assessing the vulnerability of buildings have been defined to achieve different levels of knowledge according to the nature of the case study. In Italy, survey tools and evaluation methods based on typological recognition (called 1st level) and on the survey of characteristic factors of the seismic behaviour of buildings (called 2nd level) have been created and used for the territorial risk analysis on several occasions.

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**Fig. 1**  
Map of the City  
of Camerino. In  
"Camerino e i  
suoi dintorni",  
Aristide Conti  
(1872).



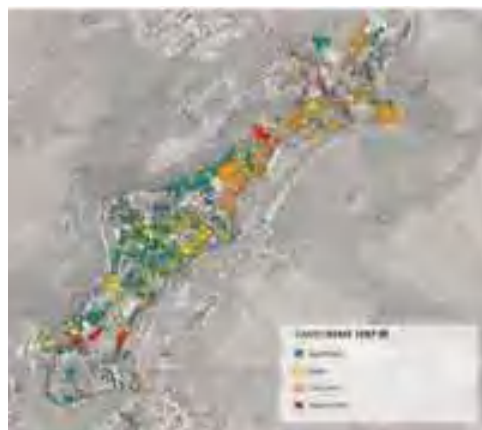
**Fig. 2**  
Damages related  
to the 1799,  
1997-98, 2016  
earthquakes in  
Camerino.

In-depth knowledge of the conditions of seismic vulnerability is required to carry out analysis aimed at reducing seismic risk and creating damage scenarios. This knowledge is based on the identification of the typological and morphological characteristics related to specific cases. In particular, the study carried out on the historic centre of Camerino is taken as a case study, due to its significant exposure to frequent earthquakes that cause specific vulnerabilities; various parameters affect the structural behaviour of the buildings that are arranged in clusters, following different layouts based on the orographic configuration of the site. The most relevant parameters are represented by the constructive characteristics and their evolution in history.

### **Characteristics of the case study: the historic centre of Camerino**

The historic centre of Camerino has been identified as a case study as it represents one of the most affected historical centres after the 2016 seismic events and which still has a very large "red area" (not accessible area due to the damages). Camerino has a high historical-cultural value and it is possible to find a vast amount of available data on local seismic history. This offers the opportunity to expand the horizons of research, considering a period during which the behaviour towards the earthquake has profoundly changed, also concerning the evolution of the specific reference regulations. (Fig. 1)

The city of Camerino (from Kamars: rock, fortress) is an ancient settlement of the *Umbri Camerti* and it has its roots in the Neolithic, after which it became an Umbrian





**Fig. 4**  
Typological  
classification  
of building  
clusters in the  
historic centre of  
Camerino.

stronghold. In the Roman age, it had an important role, as evidenced by the alliance treaties stipulated with the city in 309 BC which guaranteed the city considerable importance until the third century. As bishop's see from 465, it had a vast ecclesiastical jurisdiction for over a millennium. After the Lombard conquest, it was the capital of the marquisate and the duchy which was part of the one of Spoleto (6th - 8th century). Charlemagne elected it as the capital of the homonymous March, which stretched from the Apennines to the Adriatic Sea. First Ghibelline municipality, later it became a Guelph stronghold and seat of the pontifical legislation of the Marca (1240) for which in 1259 it was destroyed by Manfredi's troops. The city was rebuilt by Gentile da Varano who established in Camerino the foundations for the lordship of his family since the second half of the thirteenth century. Under the same *Signoria Da Varano*, which lasted until the middle of the 16th century, Camerino experienced the most intense political and cultural period, interrupted only by the ousting of Giulio Cesare Da Varano by Valentino (1502) which, however, did not prevent the son Giovanni Maria to recover the state in 1503 and to acquire the title of Duke. From 1545 the city returned under the direct dominion of the Church as the capital of the Apostolic Delegation. Following the numerous sixteenth-seventeenth-century amalgamations, of the oldest fabric, there are only precise testimonies of the medieval phase, brought to light under the plaster through "ruderization slots". Over the centuries, the town has been heavily damaged by frequent earthquakes, with epicentres in the central and central-southern Apennines. The most significant are those of the eighteenth century (1799) when considerable damage was recorded to the buildings in the historic centre. During the nineteenth and twentieth centuries, the episodes followed one another in particularly close sequences (1979 and 1997) which seriously damaged most of the historic centre of Camerino. The recent 2016-2017 seismic sequence has again damaged the same buildings located within the historic centre, where a large red area has been established, which is still present today. (Fig. 2)

#### **Geological setting of the area: seismic hazard**

The historic center of Camerino develops essentially on a arenaceous formation. Around the historic center there are a lot of landslides, which is a frequent condition for all the towns in the Marche region morphologically located on a hill. These landslides, in addition to their geomorphological significance, also have an anthropic component. Many of the landslides we see today have recently reactivated for anthropogenic reasons, that is why they are linked to the transformation of land use.



The geomorphological seismic hazard is connected to the different seismic response of bed-rock on which the historic center is built. Different and/or severely fractured geological formations or the presence of thick unconsolidated sediments can generate seismic waves amplification phenomena or, in general, different acceleration peaks during earthquakes. In Fig. 3 it is possible to observe how part of the northern sector of the arenaceous relief is characterized by very thick cover deposits, at places even higher than 10mt. The red lines indicate two passage areas: these anomalies could indicate the presence of one or two faults, and if it is not, they are still two weak areas in which the substrate is deeper and there is a clear distinction between one side and the other. (Fig. 3)

What we can expect from the damage survey is that the buildings located in the deeper bed-rock areas should be the most damaged. Very significant damages should be also found in the buildings located along the edges of the arenaceous plate, where seismic amplification phenomena are associated with the morphological effect connected to the presence of steep escarpments.

#### **Description of the main elements that determine the high vulnerability of the historic centre of Camerino**

The orographic characteristics of the site on which the historic centre of Camerino lies and the stratification of the building fabric, subject to important replacement or reconstructive operations, are factors of local vulnerability. The first analysis concerned the development of the building clusters as a result of a series of transformations, starting from the elementary cells that developed in a complex system, characterized by the sharing or simple juxtaposition

AEDES		MASONRY/ACTIONS					
RESULT		PERPENDICULAR		VERTICAL		COPLANAR	
A	0,1	A	0,05	A	0,05	A	0,05
B	0,2	B	0,1	B	0,1	B	0,1
C/D	0,3	C	0,15	C	0,15	C	0,15
E	0,4						



**Tab. 1**  
AeDES correctives.

**Tab. 2**  
MQI Correctives.

of vertical and horizontal elements. The structural behaviour is not ascribed to the individual structural units and therefore a knowledge of the evolution of the building clusters is essential (Greco, 2018).

As a first fundamental step for the description of the building clusters, we classified them according to their position and their shape (Fig. 4):

Linear cluster with serial fusion along a prevalent axis:

1. Along the walls
2. Double-sided with internal courts
3. With specialized buildings

Polar cluster with fusion around one or more courts

1. One court or compact
2. Two or more courts
3. With open court on path
4. With specialized buildings with several courts

Specialized aggregates with particular fusions

These categories have been designed on the historic centre of Camerino and follow what has been its evolution, however, they can be reapplied or readapted to all historic centres with similar morphology and evolution such as many other historic centres in the Marche region that have the same conformation (sandstone podium area). (Fig.4)

Currently, the buildings rarely exceed three floors above ground and the elevations, mostly without overhangs, are characterized by the clear prevalence of solids over voids.

The fronts overlooking the main roads are mainly covered with plaster, the presence of which makes it difficult to define the type of historical building systems used. However,



almost exclusively from the ‘minor’ fronts, masonry made of pebbles and small rubbles bonded with abundant mortar can be observed, sometimes regularized using brick courses. It is possible to distinguish numerous changes made in recent times, some of which, in addition to compromising the general figurative quality of the historic centre, alter the structural behaviour of the individual buildings. We refer to the punctual elevations, to the additions, to the restorations carried out with technologies that are not very compatible with the traditional ones and to the prevailing practice of replacing traditional materials with modern ones.

A fundamental step in the analysis of the current state of the buildings is represented by the historical-typological characterization of the wall samples. This dating was mainly based on a diachronic analysis carried out by crossing historical maps and reconstructions of the evolution of the buildings. The recurring types of masonry for each historical period are shown in figure 5; the sampling was carried out in the lower areas of the buildings without plaster on the façade. A total of 44 samples were analyzed and an analysis sheet was drawn up for each.

Its contents can be summarized in:

Part 1 - Location and identification of the masonry

Part 2 - Survey of the wall typology:

- a. panel geometry;
- b. characterization of the panel and section materials;
- c. characteristics of the bedding mortar.

Part 3 - Qualitative observations and mechanical parameters. (Fig. 5)

Proceeding to analyze the masonry building as a whole, what will most affect its behaviour concerning horizontal actions will be the level of regularity and box-like nature of the building. The presence or absence of these two conditions guarantees a correct distribution of horizontal actions, the inhibition of the activation of local mechanisms and the development of global resistance mechanisms.

After the direct inspection, it can be said that the buildings in the historic centre of Camerino present significant levels of damage; these levels are analyzed through the intersection of information synthetically collected within analytical files:

- a. Information from the AeDES forms for ordinary building;
- b. Descriptions of the correct parameters in the construction of a wall system and that determine the MQI values (Borri, 2019) (Fig. 6).

Furthermore, information is collected on the characteristics of the cluster systems:

1. position in the urban context, to understand the possible interaction between different buildings under earthquake, the position of the buildings in the urban context must be

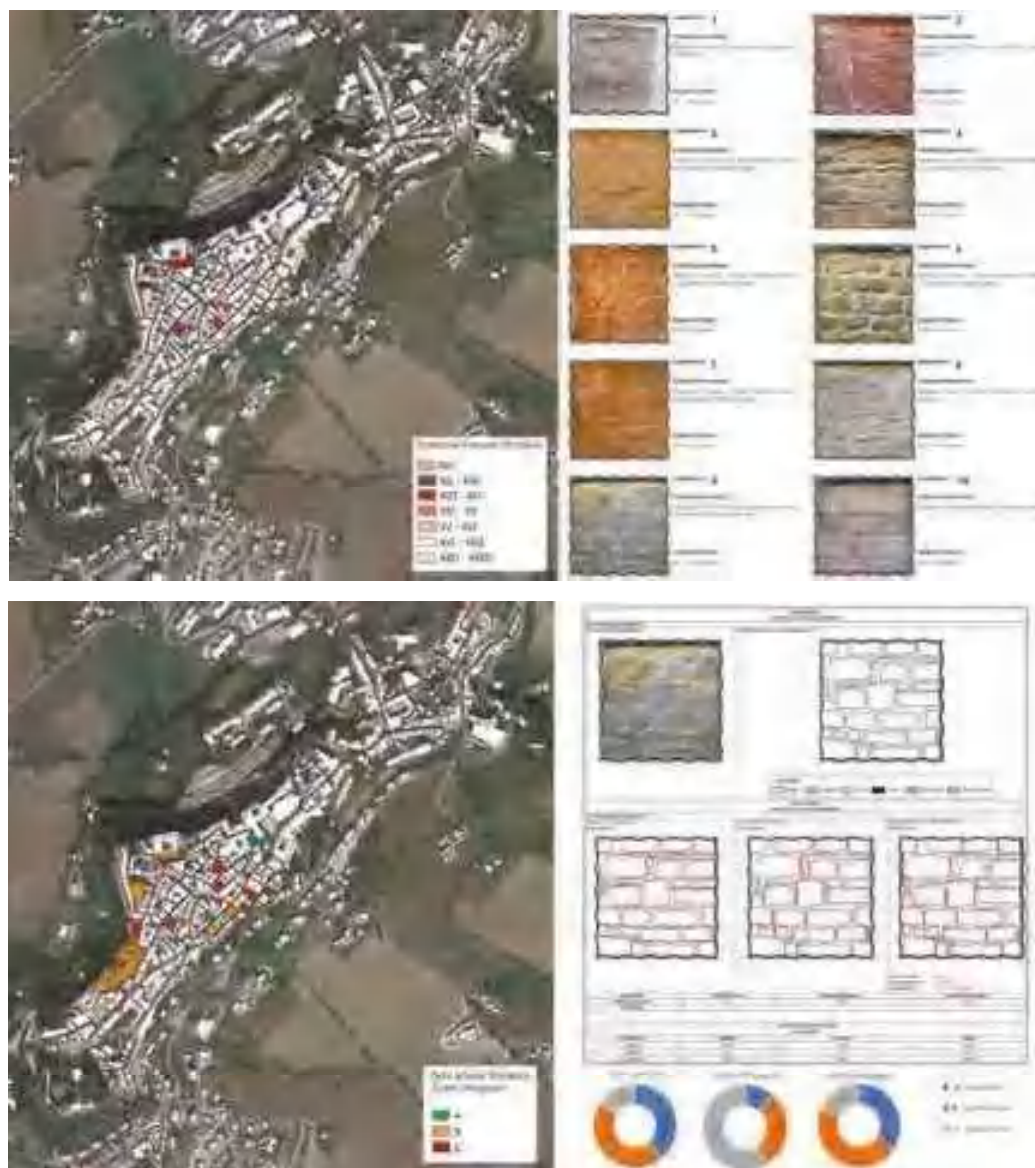


Fig. 5 Masonry typology identified on the basis of the construction period.

Fig. 6 MQI Results: Orthogonal Actions. The map shows the results concerning the masonry quality related to the orthogonal actions.



**Fig. 7** Identification of the building clusters analysed and vulnerability index sheet.

**Fig. 8** Identification of the vulnerability of the building clusters: from very low (blue) to maximum (red) vulnerability. This classification provides a starting point for the characterization of the fragility of the clusters.



**Fig. 9**  
Identification of the vulnerability of the building clusters with AeDES and MQI correctives applied: from very low (blue) to maximum (red) vulnerability.



taken into consideration (isolated, adjacent/statically independent structures, in connection/structures interacting);

2. photographic documentation of the cluster;
3. volumetric reconstruction or the elevations of the entire cluster;
4. total number of storeys including any basements;
5. average storey height;
6. number of basements;
7. average storey surface;
8. age of construction;
9. prevalent use;
10. irregularities in plan and elevation

Following this description carried out for each cluster highlighted in figure 6, a methodology has been applied for the assessment of vulnerability, through partial indices relating to the constructive deficiencies detected such as disconnections in plan, vulnerability to shear forces, hammering, etc. (Mochi-Predari, 2016). (Fig. 7)

To obtain a constant and continuous control of the information, these must be collected with the help of analytical sheets, whose information is associated with a georeferenced system (G.I.S.) in such a way as to be able to query this system having direct feedback on the cartography. The graphing of the questions on the cartography allows evaluating whether within a given urban fabric there are critical areas, from the seismic point of view, linked to factors congenital to the geological zone in which they are located, to the construction types present in that urban sector, among the possible examples, the general state of conservation.

The survey of characteristic factors of the seismic behaviour of the buildings made it possible to identify one of the most vulnerable and highly damaged elements in the wall system. The materials, the installation systems and the mortars of the masonry were analysed: the result is limited use of the “rule of the art”, which is linked the Masonry Quality Index (MQI) (Borri, 2019). The observation of the samples and the subsequent construction of a chrono-typological abacus of the walls present in the buildings in the historic centre allowed a careful reading of the state of affairs. For each masonry sample, an MQI was defined which separately evaluates the responses of the masonry panel for the different types of actions. In Camerino, the walls that have a higher MQI are those in squared stone (generally of medieval dating), while the walls of lower categories are more frequent, especially concerning the orthogonal actions to the wall plane. In summary, the most evident deficiencies are related to the response of the wall systems to seismic actions, as they are not able to withstand events characterized by high intensity and considerable accelerations, amplified by local factors.

The analyzes derived so far and the information obtained both from on-site observation and from the hypotheses put forward on the historical evolution of the buildings allowed us to apply a methodology for identifying the vulnerability of individual building clusters (Fig. 8). This first application on GIS has provided us with a starting point for the characterization of their fragility, to which further information relating to the levels of damage collected by the AeDES forms and relating to the sheet for the evaluation of the masonry quality index was added (Fig. 9), to be able to provide, with the data collected, a scenario that is as faithful as possible to the reality experienced. Using as a basis the map related to the vulnerability of the clusters examined, the damage described by the AeDES has been categorized according to weights gradually increasing according to the severity of the outcome as reported in tab. 1. A similar procedure was carried out for the results related to the MQI: it is clear how the quality of the masonry affects the overall behaviour of the cluster. For this reason, a correction coefficient directly related to the masonry quality index is proposed to be applied to the global vulnerability described above. This corrective coefficient takes into account the results of the MQI related to perpendicular, vertical and coplanar actions whose relative score is added to



the vulnerability index (Tab. 2), considering the masonry analysis a deteriorative condition of the behaviour overall of the aggregate. Note, therefore, that the aggregate's vulnerability index is closely related to the masonry quality and, consequently, to the type of masonry from which it is formed.

The total score was then normalized to obtain a result comparable with the one relating only to the methodology applied. The final result is, therefore, a qualitative description of the vulnerability ranging from a very low to a very high level.

These results allow us to have a general picture of the situation in the historic centre, and then to be able to compare the information obtained. As can be seen from a first comparison between the two maps shown below, the information relating to damage and masonry quality provide a more precise picture as they derive from more in-depth analysis, however, they give a worse vulnerability result than the first, probably due to the conditions associated with the individual structural units and the local parameters associated with them. (Fig. 8)(Fig. 9)

### Conclusions

In formulating judgments relating to seismic behaviour, vulnerability and verifying the safety of historical aggregates, a careful reading of the data is required through integrated automatic procedures, looking for constant feedback in the characteristics and the actual state of each specific artefact.

The analysis of the typological-structural survey on the clusters allowed the identification of a series of effective vulnerability characteristics common to the buildings located in the historic centre of Camerino. Through the considerations inherent to the morphology of the aggregate, the construction quality and the transformation phases, the particular weaknesses of the buildings were identified. The in-depth studies on the knowledge of the masonry quality, of the connections and discontinuity between structural elements, have proved indispensable as they are fundamental aspects to characterize the critical elements. Finally, through the cataloguing and characterization of the actual damage, the vulnerabilities that exist on the building were taken into account, allowing also to add the local parameters relating to the individual structural unit. The study, therefore, is divided into several interrelated levels that are necessary to carry out analyzes aimed at reducing seismic risk and constructing damage scenarios that can be useful, on a territorial scale, for the possible definition of a "ranking" of the clusters based on the identified vulnerability and, therefore, of an intervention priority.

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