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3D multilevel approach for the seismic risk of historic centers

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3D multilevel approach for the seismic risk of historic centers

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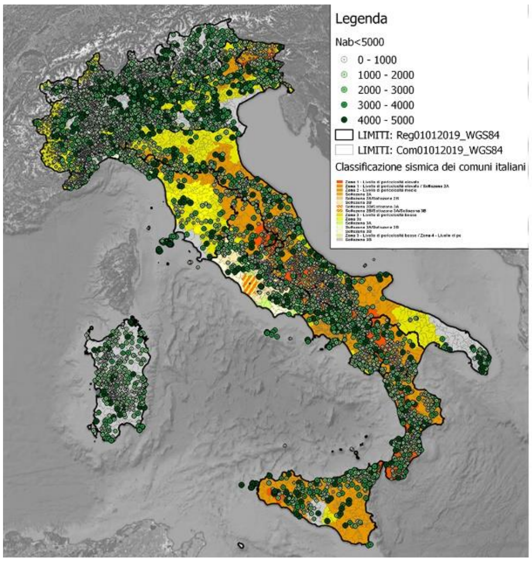
Abstract. Italy is a country characterized by urban realities that present an extremely heterogeneous morphology generated by the development of the buildings in different historical periods. Due to their geographical position in the Italian orographic context, they are extremely exposed to seismic risk whose mitigation and reduction is a topic of particular interest. The representation models for displaying the main vulnerability phenomena provide important support for the analysis of structural vulnerability. With this awareness, the aim of this research is the definition of an integrated multilevel tool capable to manage, analyse and represent the multiplicity, heterogeneity and complexity of the data necessary for the evaluation of the seismic vulnerability of masonry buildings constituting the historic centers. Through in-depth knowledge and the use of parametric modelling systems (BIM) it is possible to determine the most likely collapse kinematics, on the basis of information deduced from a knowledge process, and therefore to evaluate the levels of seismic vulnerability of each structural unit both from a qualitative and quantitative point of view. This methodology is tested on a case study - San Rocco Village in Sora (FR) – and results are exposed.

1. Introduction

The debate on the preservation of historic centers has reopened with vigor after the last seismic events that affected the Italian municipalities. They are considered “environmental monuments” to be protected and preserved due to the originality of their urban composition. They arose during the medieval and renaissance times, and these nuclei are based on urban layout models (spindle, enveloping, multidirectional, radial) depending on the altimetric characteristics of the place of settlement (ridge, counter-ridge, plain, foothills). From an architectural/structural point of view, these historic centers are almost totally characterized by masonry buildings made with materials easily available on the construction site. They also have been subject to changes over time such as extensions, modifications and interventions compared to the initial configuration creating heterogeneous systems interconnected in aggregate solutions in which they were generated significant structural vulnerabilities. The safeguarding of these centers starts from a knowledge project aimed at highlighting the main factors that contribute to the assessment of seismic risk: hazard, vulnerability and exposure. For these reasons it becomes important to know the location of the “minor historical centers” in order to evaluate the seismic exposure. By "minor" it means those historic centers that have a population of less than 5,000 inhabitants. Therefore, not minor for the architectural and urbanistic peculiarities, but only for the dimensional peculiarities [2]. In order to conduct these analyzes it has been designed a GIS, called HT_GIS, acronym for *Historical Town_Geographical Information System*.

The system, based on the ISTAT census data and data obtainable from the sites of Regions, Provinces and Municipalities, is able to display in overlay the information from the associated database. It graphically returns the location and size for number of inhabitants of minor historical centers. It is obvious to overlay the INGV map of the seismic hazard with the distribution map of the minor historic centers. It emerged firstly that minor centers make up 70% of the Italian municipalities. It also clearly emerges that the minor historical centers are located in the Apennine areas in which the most recent seismic classification has attributed as value the zone 1 and 2 with the maximum macro-seismic intensity. The result is obvious because these centers were born in medieval times and located on the slopes or on top of hills for strategic reasons (fig.1).



Demographic range	Municipalities		Population	
	number	%	residents	%
from 500.000 and over	6	0.08%	7.336.149	12.13%
from 250.000 to 499.999 ab.	6	0.08%	1.923.795	3.18%
from 100.000 to 249.999 ab.	33	0.42%	4.913.191	8.12%
from 60.000 to 99.999 ab.	60	0.76%	4.614.583	7.63%
from 20.000 to 59.999 ab.	419	5.29%	13.709.350	22.67%
from 10.000 to 19.999 ab.	708	8.95%	9.747.333	16.12%
from 5.000 to 9.999 ab.	1.186	14.98%	8.369.615	13.84%
from 3.000 to 4.999 ab.	1.098	13.87%	4.278.496	7.07%
from 2.000 to 2.999 ab.	947	11.96%	2.326.553	3.85%
from 1.000 to 1.999 ab.	1.520	19.20%	2.211.834	3.66%
from 500 to 999 ab.	1.095	13.83%	807.426	1.33%
less than 500 ab.	836	10.57%	245.648	0.41%
tot	7.914	100.00%	60.483.973	100.00%

Demographic range	Municipalities		Population	
	number	%	residents	%
less than 5000 ab.	5.497	69.45%	9.869.957	16.32%
less than 4000 ab.	5.031	63.56%	7.780.265	12.86%
less than 3000 ab.	4.399	55.58%	5.591.461	9.24%
less than 2000 ab.	3.452	43.61%	3.264.908	5.40%
less than 1000 ab.	1.932	24.41%	1.053.074	1.74%

Figure 1. HT_GIS: Distribution of the minor historic centers (M. Saccucci)

With the aim of reducing the seismic risk in which these centers are subject, it is necessary to intervene in the reduction and assessment of vulnerability, as well as in the identification of the main vulnerabilities in the preventive phase [3]. With this awareness, the aim of this paper is to define an integrated multilevel tool capable of managing, analyzing and representing the multiplicity, heterogeneity and complexity of the data necessary for the definition of the seismic vulnerability of masonry buildings constituting the historic centers.

2. 3D multilevel approach

The methodology used to reach the goal for the evaluation of the seismic risk of historic centers is divided in two types of approaches:

- *1 level - qualitative approach* based on a simplified survey and a qualitative analysis capable to define the most probable local collapse mechanism
- *2 level - quantitative approach* based on a detailed survey and qualitative analysis capable to define of the spectral acceleration of activation of the collapse mechanism.

The qualitative level is based on an expeditious visual survey and a simplified characterization of materials that constitute the input elements for an algorithm developed in Boolean language (T/F) for the identification of the most probable local mechanism of collapse of the facades of masonry buildings, the latter widely described in the literature as global overturning, partial overturning or along openings, vertical and horizontal bending. The algorithm compares the dataset of the information acquired in the survey phase with the structural peculiarities that characterize the collapse kinematics of masonry buildings in order to identify the collapse mechanism with the highest probability of occurrence [6]. The methodology therefore allows to have a 3D CAD graphic model in which to bring together the information obtained from the survey and view the results of the analysis [1].

The quantitative level, on the other hand, consists of an advanced approach for the quantitative assessment of seismic vulnerability on the basis of information deducible through detailed instrumental survey activities based on a BIM model [5]. This is a quantitative evaluation since it also associates information on the level of seismic acceleration of activation of the mechanism to the possible collapse mechanisms. This level of analysis is supported by an instrumental survey based on the use of laser scanner 3D and digital photogrammetry for the design of a BIM project for archiving data and displaying the results (fig.2).

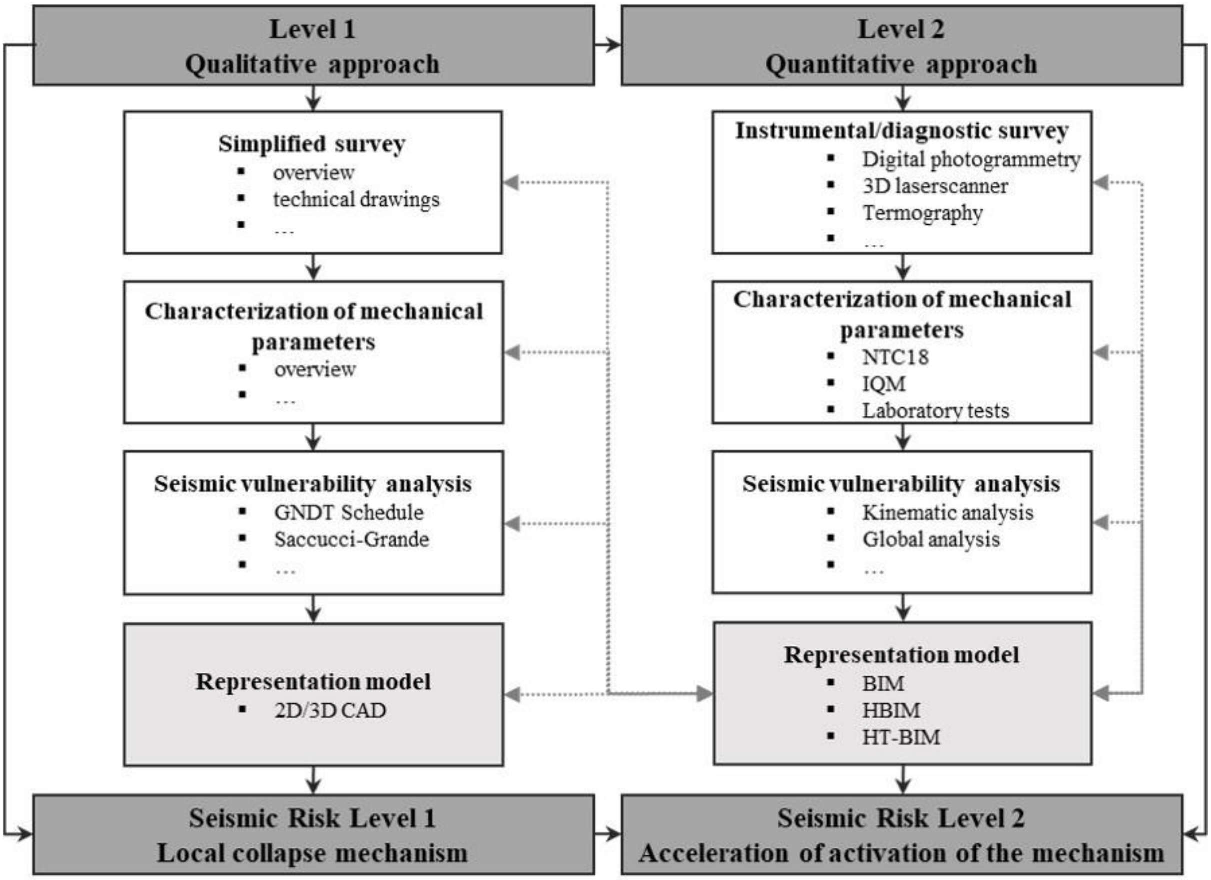


Figure 2. 3D multilevel approach (M. Saccucci)

3. Case of study

The multilevel approach proposed has been tested on a portion of the historic center of Sora, a town in central Italy in Lazio region, named “Borgo San Rocco”. It is a small village in a minor historical center of Roman origin, then medieval. It is located near the Liri river and the side of Monte San Casto. Sora is also located in an area with a high seismic hazard [7]. The village consists of two interconnected structural aggregates that flank the road.

3.1. Qualitative approach

The approach of level 1 - qualitative approach consists in a rapid survey of the aggregate improved with the archive material: in particular the documents held by the Municipal Technical Office relating to the surveys after the 1984 earthquake consisting of floor plans, sections and prospectuses. Through this information it was possible to identify the individual structural units (SU). For each of them has been identified the general characteristics of the facade such as the length of the facades, the height of the buildings, an analysis of the height of the horizontals and the alignment of the openings intended as doors and windows. For each US was compiled a survey form for the application of the algorithm developed in order to identify the collapse mechanism [4]. By associating the results with an appropriately created 3D graphic model, it is possible to visualize the types of collapse mechanisms affecting the aggregates having a clear qualitative indication of the vulnerability to which they are subject (fig.3).

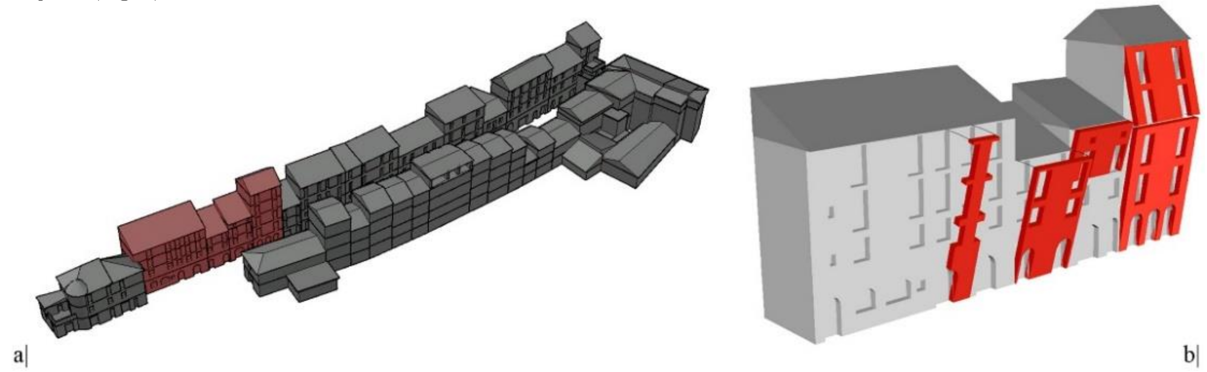


Figure 3. Qualitative approach: CAD model and display of results (M. Saccucci)

3.2. Quantitative approach

The second level of analysis is based on an in-depth and detailed survey. In particular the technique of aerial digital photogrammetry with UAV which starting from photographs allow to reconstruct a 3D point cloud with a digital process. The point cloud, imported into BIM, constitutes a fundamental support for the creation of the HT_BIM 3D model, making the modeling simple and effective [9]. In fact, in this way it is possible to model from the general to the particular by integrating in a single model all the geometric, functional, material and performance information of the elements. Furthermore, as foreseen by the proposed methodology for this level of detail, it was necessary to characterize the chemical and mechanical parameters of the materials through tests carried out in the Chemistry and Materials laboratory of the University of Cassino for the determination of the characteristics. All these data, considered as input data for the subsequent analyzes, were the basis for the realization of structural models for the execution of the linear kinematic analysis which allows to obtain the activation multiplier of the collapse mechanism and the spectral acceleration. activation of the collapse mechanism (fig.4).

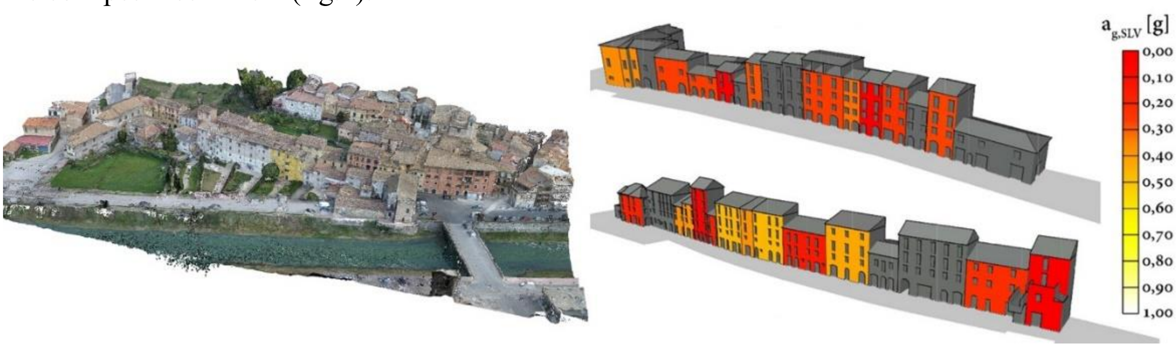


Figure 4. Quantitative approach: 3D point cloud and HT_BIM model for the display of results (M. Saccucci)

In this way, having all the necessary information, it is also possible to perform the checks required by NTC18 by comparing the capacity with the demand, thus passing from a qualitative result to a quantitative one since it also tells us whether the mechanism can be activated and consequently the level of seismic vulnerability of the buildings towards these mechanisms [8]. In fact, the diagrams show the results obtained for each SU reported on the abscissa in terms of the acceleration of activation of the mechanism, and on the same graph the value of the PGA, the peak acceleration expected at the site, is shown in red. It can be observed that most of the facades are subject to the possibility of activation of the identified mechanism. In particular, buildings that have a mechanism activation acceleration value lower than the PGA value in red are subject to activation. In other words, it is observed that most of the SU have a marked level of seismic vulnerability. The same results can be viewed in the BIM model developed dynamically and automatically, first with the color maps based on the activation value of the mechanism and then in terms of verification (red / green) (fig.5). This type of visualization allows immediate recognition and visualization of vulnerable buildings.

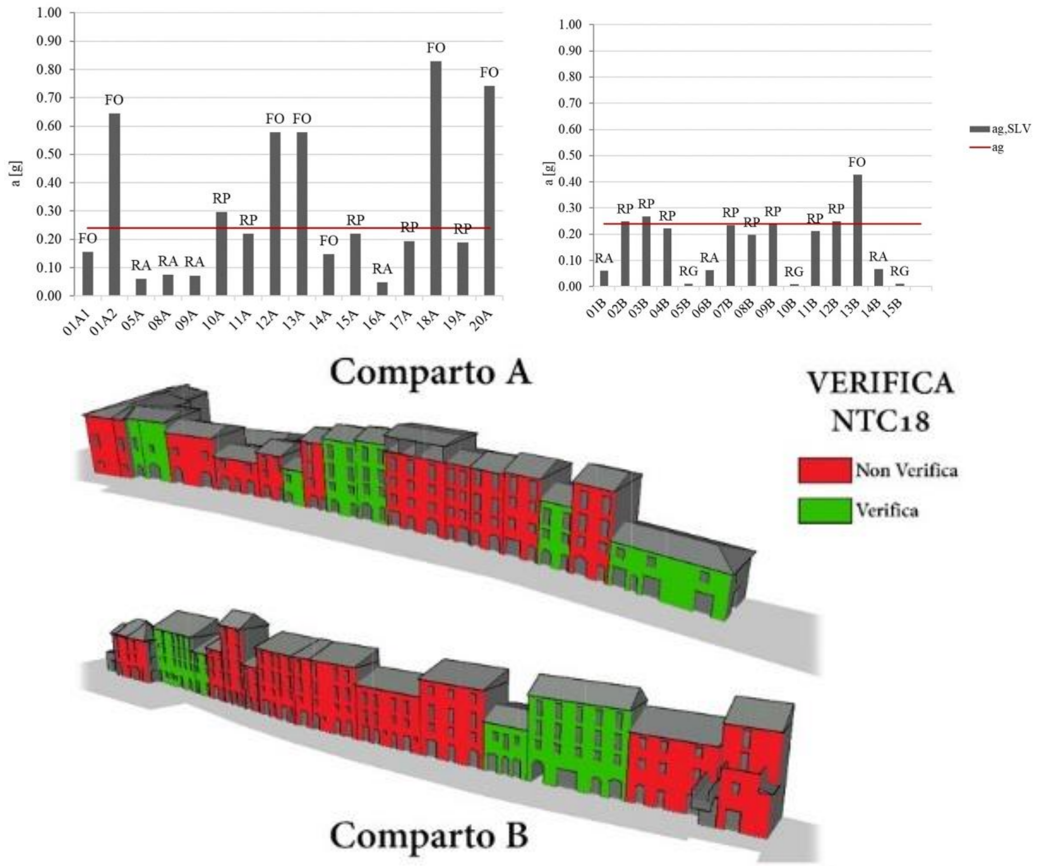


Figure 5. NTC18: PGA check for the activation of the mechanism (M. Saccucci).

4. Conclusions

The information obtained from the 2 levels is extremely important for the administrations that govern the territory as they allow to highlight which units have priority of intervention, that is most vulnerable to seismic actions. They therefore constitute a support system for technicians who have to intervene as the most probable mechanism of collapse is identified and consequently, they have the possibility to define interventions to counter them. The methodology introduced finds wide applicability in the procedures already in place in Italy for the mitigation of seismic risk. These include the CLE analysis introduced with OPCM 4007 of 2012 following the L'Aquila earthquake. It represents a system for verifying the choices made in the preparation of the Municipal Civil Protection Plan (or Emergency Plan) through the evaluation of the interference of the buildings with the connection and accessibility infrastructures that connect the strategic buildings in extreme conditions for the emergency. By interference we mean the complete overturning of the facade along the road, which would therefore lead to the interruption of the entire emergency management system. For CLE, the procedure is purely geometric. It could lead to untrue situations: in some cases, it is forced to define a building as an interfering one that in reality would not be and therefore to carry out delicate operations to change the municipal emergency plans. The developed multilevel methodology intervenes with the identification of the correct collapse kinematics thus ensuring a correct and reliable evaluation for the evaluation of the Emergency Plan. As can be seen in the application made to the Borgo San Rocco case, using the methodology proposed by CLE, it is observed that almost all the buildings interfere with the road that passes through the Borgo. By applying the proposed algorithm instead, there is a drastic drop in the number of buildings that can be considered effectively interfering. Therefore, the developed tool appears to support the choices in the safety plans.

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