Streamlining Information Transfer between Construction and Structural Engineering
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BIM-BASED APPROACH FOR SEISMIC RISK ANALYSIS

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The Italian school buildings asset consists of over 40,000 units. The most (more than 60%) were built before the introduction of the national standard on school buildings and constructions in seismic areas. The present research aims to implement a methodology that consists in an informative modelling for seismic risk analysis. The objective of the activity is to provide the policy makers of a useful tool for screening the existing building stock, in order to define the priorities of intervention. The research is divided into several parts. First of all, the most recurrent building technologies have to be defined with respect to the year of construction and the structural characteristics. Furthermore, to assess the seismic risk, the seismic hazard has also to be analyzed. Next, a multiphase process of increasing complexity has to be defined, in which two approaches of seismic analysis are tested. The first one is related to "simple" construction technologies (e.g. frame structures) where information can be collected through visual screening during inspections and through the study of the existing documentation. The second one is a more refined approach that includes non-destructive testing on site and structural analysis. Both procedures lead to the definition of BIM models.

Keywords: School building, Structural monitoring, Numerical modelling, Simulations, Seismic vulnerability.

1 INTRODUCTION

The potential of Building Information Modeling for seismic risk analysis is closely linked to BIM as a relational database of buildings information. Started from ’70 with Eastman *et al.* (2011), nowadays BIM is a methodology that is changing dramatically the AEC sector, thank to innovation in IT technology. There are many and many advantages using BIM in project and construction process: can support planning and cost estimation, management of design changes, visualization and simulation of design ideas, construction management, and building lifecycle control. Many recent researchers analyzed also BIM for Facility Management (FM) and for existing buildings (Volk *et al.* 2014, Becerik-Gerber *et al.* 2012), and some of them are focused on the use of sensors for monitoring and control of parameters for building uses (Dong *et al.* 2014). BIM represent the future of building management because is a database, which contains all the information about structural and non-structural components vulnerability (FEMA 2006). Some research has also started to define some ways in which Building Information Modelling (BIM) could assist in the assessment and mitigation of seismic risk. (Welch *et al.* 2014).

2 SCHOOL BUILDING STOCK IN ITALY

The school building heritage consists of more than 40,000 buildings, largely constructed before the introduction of the technical regulations on school building (DM 18/2/1975) and before the settlement of special requirements standards for seismic areas (Law No. 64/1974) (Tagliabue and Villa 2017). Indeed, almost 2/3 of schools were built before 1974 and before that date, there was no technical standard in force that guided the design, defining at least the performance aspects.

Accordingly, most of the existing schools were built without static verification and with a level of seismic safety not in line with current standards. Nowadays, the seismic safety is established by define the seismic vulnerability in the technical standards for constructions issued by the Ministry of Infrastructure with Ministerial Decree of 17 January 2018 (NTC – Technical Standards for Construction's structures). Summarizing, it was detected that only 48.5% of school buildings have a static certification, 56% has a static certificate of suitability and only 10.1% are built according to earthquake safety criteria. Concluding this brief overview, 50.13% of school buildings on the Italian territory are located in earthquake were affected areas with a medium-high hazard level (Figure 1).

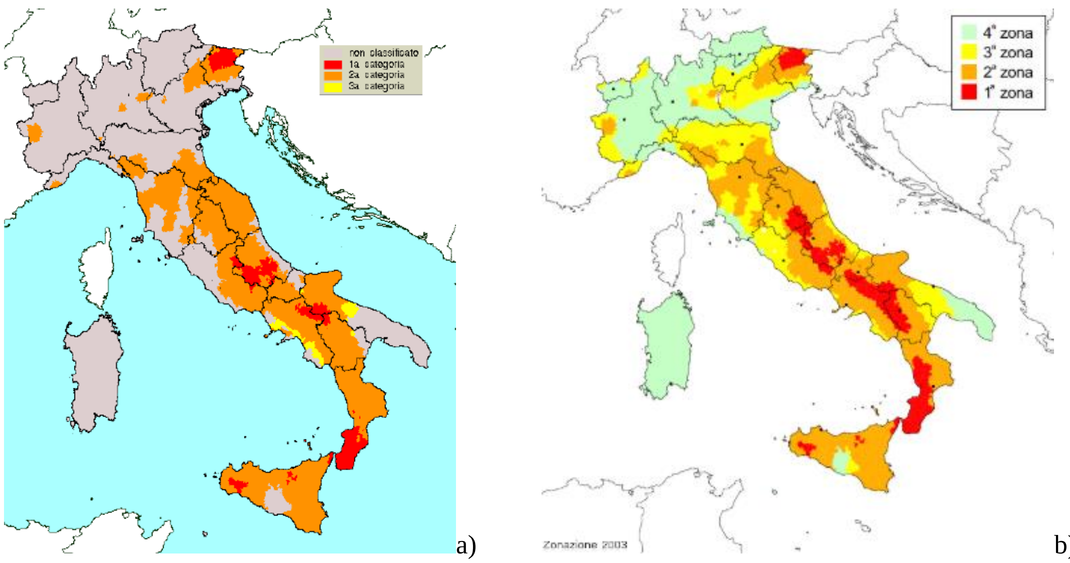

Figure 1. Seismic hazard classification of the Italian territory after the 1980 event in Irpinia region. 45% of the whole territory, 70% of the central-south territory. (a) current Italian earthquake map (OPCM 2003) (b)

3 STANDARDS ITALIAN DEVELOPMENTS

The guidelines for the assessment of seismic risk in Italy has been updated over the years on the basis of catastrophic events that have changed, from time to time, the seismic hazard classification of the territory. In 1980, the Irpinia earthquake, with about 3,000 dead and 10,000 injured, was the first tragic event in recent history and is identified as the moment when an effective policy of seismic risk prevention was firstly introduced, proposing the seismic classification of the earthquake affected areas.

Following the 1984 classification, 45% of Italy's territory is classified as a seismic risk area; about 70% of this is located in central and southern Italy. In addition to this classification, new policies are implemented to prevent and manage emergencies and disaster relief through special actions, such as: improving knowledge through monitoring networks, reducing the vulnerability of older buildings through recovery and redevelopment of the building stock, improving tools for construction interventions. After the collapse of the primary school "Francesco Iovine" in San Giuliano di Puglia (October 31, 2002) that resulted in 28 fatalities, extraordinary measures were taken and the "Plan for the safety of school buildings" and a new earthquake map were issued.

4 METHODOLOGY: WORKFLOW

In order to develop a methodology for using BIM informative model as tool for risk seismic analysis, some details should be defined.

First of all, given the vastness of the school heritage, the most common building technologies will have to be defined, also in relation to the year of construction, and, consequently, the structural characteristics, the mechanical characteristics of structural materials, the distribution of masses, etc. will have to be examined in depth. The seismic hazard, the intended use of the environment and whether any extension, modification, adaptation or improvement work has been carried out or is possible in the future shall be checked. All this information should be contained into BIM model of school existing buildings.

Subsequently a workflow will be created that systematizes two different approaches for the evaluation of the seismic vulnerability, according to a coordination defined by the information BIM modelling (1° step) and to sensors and monitoring data (2° step).

A multi-stage process of increasing complexity will be defined, in which two methodological approaches to seismic analysis will be tested: the first, simplified for "simple" building technologies (e.g., reinforced concrete chassis schools), where information will be collected through visual screening during inspections and through the study of documentation. The second will be further investigated through non-destructive testing and survey. Both procedures will lead to the definition of a new BIM model and will compare the results obtained.

This methodology will lead to use of BIM informative modelling for seismic risk analysis with the final objective of providing a useful tool to asset managers of buildings for the implementation of a screening on a given building stock, in order to define the priorities of intervention.

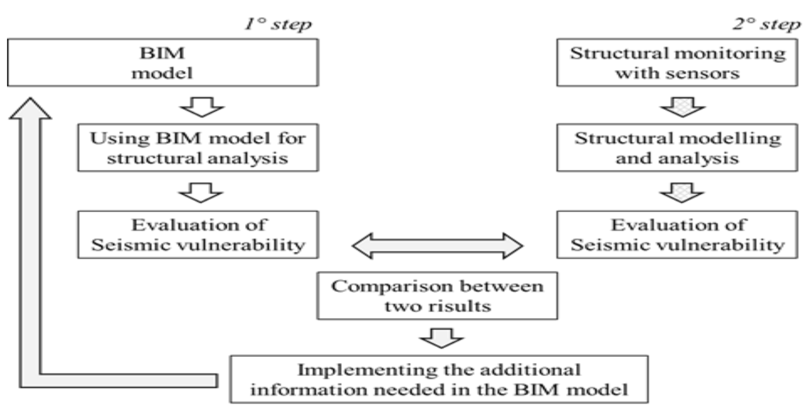

Figure 2. Workflow that shows three different paths of the research.

The experimentation will be examining in depth on selected case studies. Finally, the modalities of interoperability between the different systems and software used will be defined and a method to support the public administrations to define the intervention priorities as well.

4.1 BIM For Structural Analysis

The BIM models can be easily used for structural analysis because, starting from the export of the .ifc model from the architectural BIM software, they contain information on the geometry of the structural elements (beams, pillars, etc.), on the constraints and are updated according to the extension or renovation work carried out over the years. From the BIM model you can directly export the structural 3D model, which can be used to carry out the first structural analyses. (Alirezaei *et al.* 2016). In order to deepen the analyses, it is possible to insert further data such as, for example, the characteristics of the materials, the distribution of the masses, in order to proceed with a general evaluation of the stiffness and the seismic responses of the structure.

The BIM model preparation phase is the most delicate part, because it is necessary to identify the construction technology, the year of construction, the geometric characteristics of the structural elements and mechanical characteristics of the materials (in this case they were not available), the distribution of the masses, etc.

This research will be carried on using the Revit model of an existing secondary school, where the structure of the building and available information on materials are presented.

4.2 Structural Monitoring

Monitoring of structures consists in a step of critical assessment for the structural conditions and employs sensors for measuring physical variables (signals). Signals are sampled (digitalization phase) and processed through amplifiers and filters. For the aim of the present research two types of investigations on the real structures are envisaged. The first one is aimed to evaluate the structural scheme and the components through the existing documentations (design tables and reports). During this first phase the material characteristics have been also assessed: for the concrete material that characterizes the large part of the school asset in Italy the sclerometer will be used.

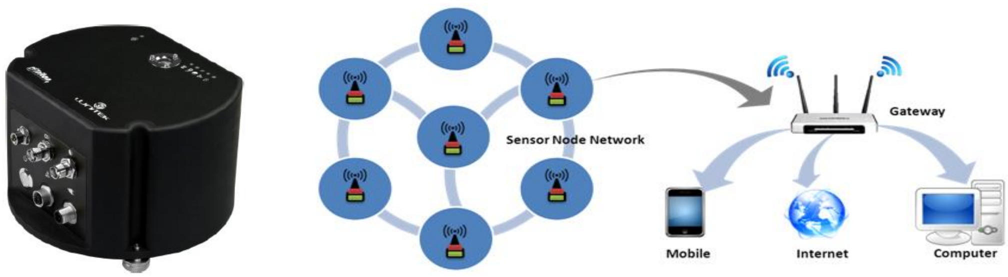

Figure 3. Tools used for the 2° step of the research (wireless sensor network).

In the second step, a wireless sensor network (Figure 3) will be used for collecting the dynamic characteristics of the structures. Indeed, the accelerations collected at different position on the floors can be processed to compute and extract the frequency characteristics of the structures and the vibration shapes.

Both phases will be useful for implementing the numerical model of the structure by using the assessed resisting scheme, materials constitutive models and so on. Then, the validation of the model will be performed through the independent dynamic analyses performed through the wireless sensor network. In particular, the natural vibration frequencies and the mode shapes will be used during the validation procedure.

4.3 Structural Modelling and Validation

The structural model will be developed using the finite element technology starting from the structural scheme and the dimensions defined in the previously determined BIM model. The characterization of the materials will allow the definition of the constitutive model and the appropriate characteristics that will consider in this preliminary stage the linear domain.

The model will then be validated using experimental tests and data collected by the wireless sensor network. In particular, the comparison between the fundamental frequencies and the vibration modes will help to consolidate the procedure. In Figure 4 the numerical model of a building frame is reported.

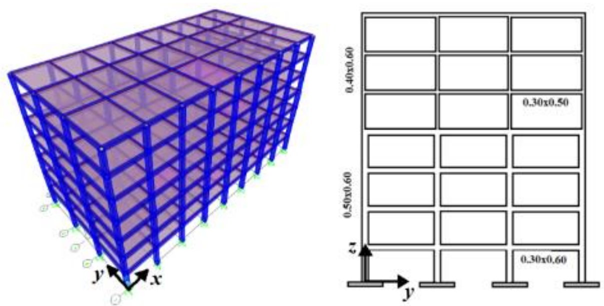

Figure 4. Numerical model of a building frame.

4.4 Seismic Vulnerability

Seismic vulnerability "represents the propensity of a structure to suffer a certain level of damage facing a given seismic event". The current Italian regulations require the assessment of seismic vulnerability for all public buildings and, currently, promote funding for the redevelopment of public buildings, with particular reference to schools. The parameters that can influence seismic vulnerability are the structural type, age of construction, number of floors and maintenance status of the building. In particular, the following vulnerability index can be computed as:

$$\varsigma_E = \frac{F^*}{F_{NTC}} \tag{1}$$

Where F* is the maximum bearable seismic action and FNTC is the seismic action that should be used for designing the same structure accordingly with the current Italian standard DM NTC 2018. The value at the numerator can be computed through different methodologies at increasing complexity. For regular structures, static nonlinear analyses (pushover) could be selected and the capacity curve in Figure 5 can be obtained.

The transition from the linear range could be selected as the maximum bearable seismic action. However, it is worth noting how the standard does not give any other prescription about modelling and it can be interpreted as an implicit recognition of the uncertainties of the problem and the singularity of each structure.

The evaluation of the seismic capacity for the structure should allow estimating a safety margin moving the problem from the seismic hazard characterization at the site to the structural fragility. Such perspective could be also useful for the national authority for tracing the general condition of the existing building asset, built often more than fifty years ago, in times when earthquake engineering was less developed. Conventional symbols should be adopted and used consistently.

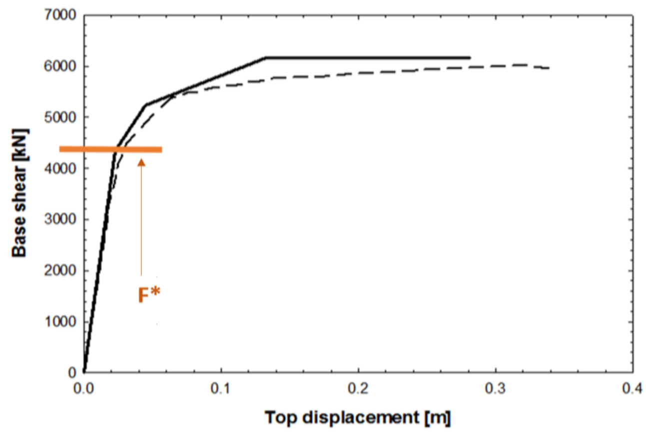

Figure 5. Capacity curve.

There is no constraint on use of units. If they are used as mathematical symbols, standard English letters like x are to appear as x (italicized) in the text.

5 CONCLUSION

The methodology presented defines a path that allows a faster and more efficient evaluation of the coefficient of seismic vulnerability of the building assets managed with the BIM. This allows managers and owners to have a valuable tool for evaluating intervention priorities, based on the deficiencies and seismic risk highlighted. The work carried out has led to the definition of the necessary information detail for a first and second analysis of the models of existing buildings.

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