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# PELL-SCHOOLS A STANDARDIZED AND INTEROPERABLE PLATFORM FOR THE SEISMIC VULNERABILITY AND ENERGY EFFICIENCY DATA MANAGEMENT OF ITALIAN SCHOOLS

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**Abstract**

*PELL, Public Energy Living Lab, is a platform conceived to support the Public Administration in Italy towards the definition and implementation of interventions on public buildings, aiming to jointly pursue their seismic safety, energy efficiency and environmental certification.*
*This paper presents the on-going activities for the development of the platform PELL-Schools, focusing, in particular, on the "Seismic-Response" module that aims to become a standardized and interoperable database for the collection and collation of relevant data for the seismic vulnerability assessment and for the seismic monitoring of Italian schools.*
*In order to test, tune and modify, if necessary, the proposed PELL-School Seismic-Response module and to contribute to its implementation on Italian school buildings a Working Group has been set up involving several Italian municipalities and stakeholders.*
*The paper concludes with a call to action inviting researchers working on the seismic vulnerability assessment and monitoring of strategic buildings to join the Working Group to contribute their knowledge towards the common goal of guarantying the seismic safety of schools and other strategic buildings in Italy.*

**Keywords:** School Buildings; Geodatabase; Standardization; Interoperability, Seismic Vulnerability Assessment; Seismic Risk; Public Administration; Energy Efficiency

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## 1 INTRODUCTION

The Italian Ministry of Education and Research (MIUR) permanently guarantees the access and reusability of the data of the national education and training system, making accessible in open format, among others, the data from the National School Building Registry System (SNAES). According to SNAES data, the portfolio of Italian schools includes 40.151 actively operating buildings belonging to local authorities, out of which: about 50% were built before 1970; 46.8% do not hold a static safety certificate; 59.5% do not hold the fire prevention certificate; and 53.8% do not hold the certificate of viability/habitability. The situation is indeed critical. As far as the seismic vulnerability of school is concerned, the situation is possibly even worse despite the several initiatives undertaken by the Italian Government. After the 2002 earthquake in Puglia and Molise, the directive of the President of the Council of Ministers (PCM) n. 3274 of 20 March 2003, referred hereafter as OPCM 3274 [1], reclassified the entire national territory into four areas with different level of hazards (removing the non-seismic areas) and introduced the obligation for the owners to proceed with the seismic verification of strategic buildings and of buildings relevant for civil protection purposes, including school buildings. Specific funds for extraordinary interventions, including seismic checks and first urgent interventions, were made available[1], and were allocate by the Civil Protection Department - through the Regions – for financing the seismic checks of about 2.300 school buildings (out of the 40.151 building patrimony). Furthermore, the Regions and Municipalities carried out further seismic checks of school buildings with their own funds. At the moment the Italian Civil Protection Department is digitizing the summary data of the checks carried out in order to establish a centralized database associated with ARES, the *Regional Registry of School Building* (in Italian, "*Anagrafe Regionale Edilizia Scolastica*")[2].

To support this process, ENEA intends to make available all the technologies and experience gained, thanks to the PELL experience, to contribute to build an interoperable database of Italian school buildings throughout the national territory. PELL, Public Energy Living Lab, is a platform conceived to: a) achieve a minimum standard of building knowledge: b) monitor and evaluate the state of art of buildings and performances; and c) support the Public Administration (PA) in Italy towards the definition and implementation of interventions on public buildings, aiming to jointly pursue their seismic safety, energy management efficiency [2]. PELL-IP, the platform for the census and monitoring of Public Lighting at national scale, is already a successful reality in Italy (since 2019).

This paper presents the on-going activities for the development of the *PELL-School* platform, focusing, in particular, on the "Seismic-Response" module, referred hereafter as *PELL-School-RS* that aims to become a standardized and interoperable database for the collection and collation of relevant data for the seismic vulnerability assessment and for the seismic monitoring of Italian schools. As far as the seismic vulnerability assessment is concerned, *PELL-Schools-RS* will faithfully replicate and build on the data structure of the official form [3] defined by the Italian Presidency of the Council of Ministers (PdCM), Department of Civil Protection, for the seismic vulnerability assessment of strategic buildings. The inclusion in *PELL-Schools* of additional input data, aimed at identifying critical vulnerabilities and at estimating a risk class and the expected average annual loss (EAL), before and after seismic retrofitting interventions, is proposed in line with the approach officially adopted in Italy for the classification of the seismic risk of residential buildings [4].

[1] The Fund of 200 million euros was implemented through the opcm n. 3362 of 8 July 2004 and no. 3505 of 9 March 2006

[2] Quoting from - http://www.protezionecivile.gov.it/attivita-rischi/rischio-sismico/attivita/sicurezza-scuole

The paper also presents the Key Performance Indicators (KPIs) indicators included in *PELL-School-RS*, namely: *Static KPIs*, providing a measure of the building seismic vulnerability and expected "nominal" risk (Section 4.1), and *dynamically computed KPIs* (Section 4.2) that aim to provide a quasi-real time estimation of the extent of earthquake-induced damage. The KPI assessment is performed in *PELL-School-RS*, at different level of reliability, Tiered approaches, based on the state-of-the-art methodologies and via a simplified analytical-mechanical approach referred to as SLaMA method [5], [6] depending on the level of knowledge achievable and on the information available for each school.

In summary, as showcased in the paper *PELL-School* aims to become a national database/cadaster of school buildings, working as:

1. a standardized and homogeneous geospatial repository of identity, consumption and seismic vulnerability data of Italian school buildings, where data are structured according to ad-hoc technical specifications from AgID[3] the Agency for Digital Italy, a technical agency of the *PdCM*;
2. an interoperable platform that, thanks to the development of appropriate communication protocols and webservices, allows for a two way data exchange and update with other existing DBs;
3. a tool for monitoring the service performance and the residual functionality of schools for both business-as-usual and post-disaster times.

## 2 PELL PUBLIC BUILDINGS – ENERGY AND SEISMIC RESPONSE LIVING LAB

Since several years ENEA has been promoting and boosting the digitization of data and information related to the public administration assets. Particular focus has been given to energy-intensive infrastructures (such as street Public Lighting) and to the strategic infrastructures (e.g. school buildings, hospital systems among others) and/or critical for the smart management of cities and territories.

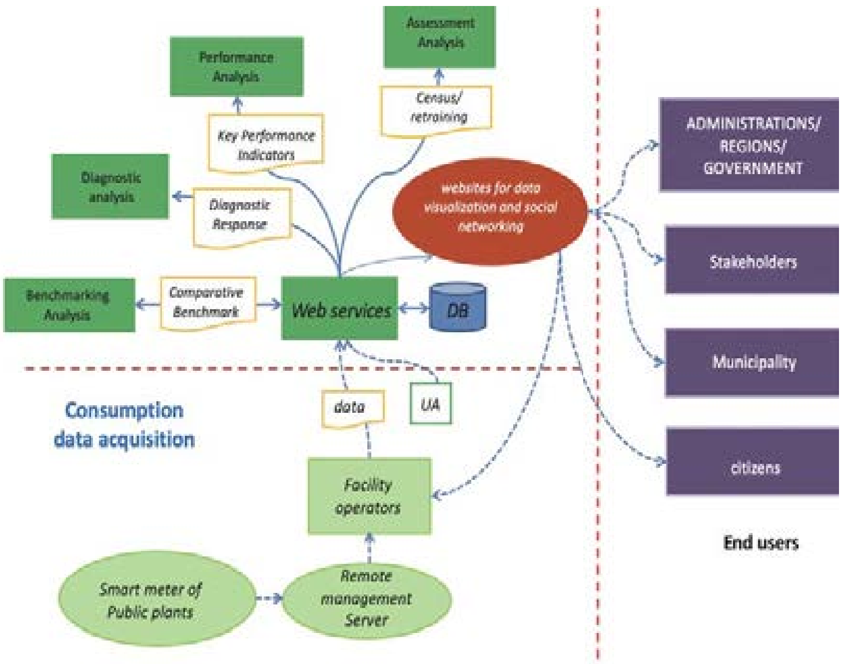


Figure 1. PELL Platform, ICT layout.

[3] Agenzia per l'Italia Digitale (https://www.agid.gov.it/)

The goal is to promote a more efficient and effective management of these infrastructures and associated services, through the development and adoption of new methodological and technological solutions, allowing to provide to the stakeholders a set of management tools, embedded in the PELL platform, that can support and inform their decision-making processes about the adoption of targeted development goals.

Towards that the idea is to automatically and constantly assess, in a uniform and standardized way, at both national and local level, both the physical conditions of the structure or infrastructure under analysis as well as the functional ones, the latter by monitoring the quality level of the service provided.

The PELL platform, developed thanks to the System Research Program Agreement under the Italian Minister of Economic Development, MISE, is made available free of charge by ENEA. The vertical PELL platform is a smart city as-a-service platform, whose general architecture defines the retrieval of data from different infrastructures and managers and the creation of a series of services for end users (Figure 1). The PELL platform is structured to operate both a static mode, to support the census of the identity data of the infrastructure, and in a dynamic mode, to support the continuous monitoring of the structure/infrastructure functioning.

## 3 PELL-School-RS DATA STRUCTURE

Figure 2 presents the data structure proposed for the *PELL-School-RS* module.

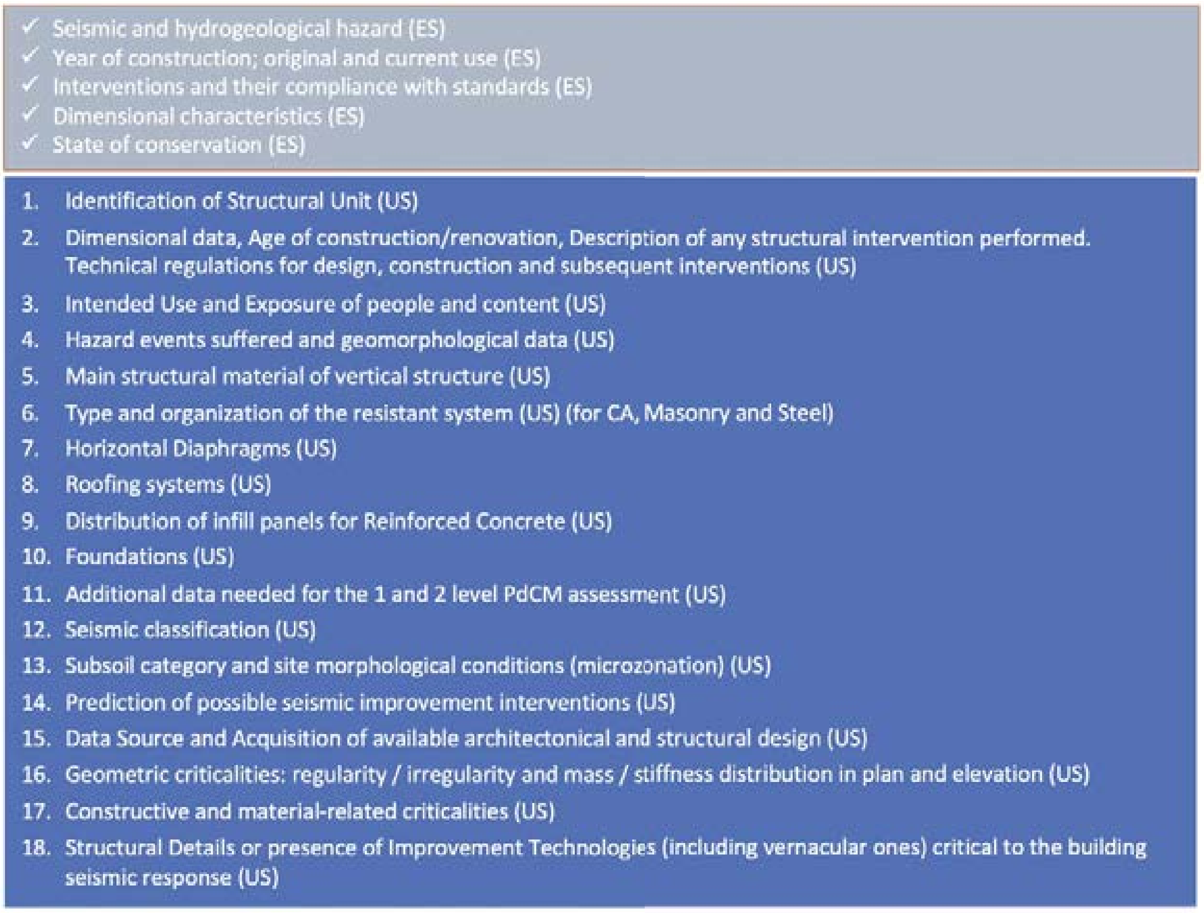


Figure 2. Main group of data included in the *PELL-School-RS* module.

In line with the structure of the ARES DB, some group of data (i.e. those included in the grey box in Figure 2) are acquired at building level, while all the others (fields from 1 to 18 in the blue box in Figure 2) refer to the Structural Unit (US, i.e. *Unità Strutturale* in Italian) and therefore need to be collected and collated for each one of the US identified within the school building.
A *Structural Unit, US* (Figure 3b), is identifiable by the homogeneity of the structural characteristics and therefore distinguishable from the adjacent buildings by these characteristics and also by the difference in height and/or age of construction and/or staggered floors, etc. The US is also the reference survey unit for *PdCM Level 1 and Level 2 forms* [3].
A full presentation of the data included in *PELL-School-RS* is out of the scope of the paper.
In the following a brief overview is provided on:

1) ARES DB, *PdCM Level 0* and *PdCM Level 1-2 forms* [3], and other "institutional" forms such as [4] and [7], that have been taken as a reference to build the data structure of *PELL-School-RS* module;

2) the proposal of additional data to be collected in order to identify the constructive, material and geometric criticalities and peculiarities that might significantly affect the seismic response of a building.

## 3.1 Data sourced from existing institutional forms

As mentioned *PELL-School* is interoperable with ARES Database (*Anagrafe Regionale Edilizia Scolastica*) that is part of the National School Building Registry System, SNAES. ARES is managed by the Italian Regions and is continuously updated by Municipalities, Provinces and Metropolitan Cities through a user-friendly graphical user interface (Figure 3).

ARES includes two different data structure, namely: a *Building* and *US* (Structural Unit) *Form* dedicated to the survey of data related to the conditions of the school building; and a *PES Form* (i.e. *Punto di Erogazione del Servizio Scolastico,* in Italian) dedicated to the collection of data relevant to the school consistency and functionality (one school building might have multiple PES, e.g. Figure 3a).

The *ARES Building Form* and *US Form* have to be filled in by the local authority owning/responsible for the school. The *ARES PES Form* has to be filled in by the headmaster. Figure 3 shows an overview of the ARES Platform dashboard and of some images extracted from an ARES manual.

*ARES Building* and *US Form* includes 8 sections. *PELL-School-RS* sources data from the first three of them, namely:

- *Section A,* including: identifier data of the school building, comprising a unique ID;
- *Section B,* including: identifier data of each Structural Unity, US; structural information of the US, i.e. material and typology of the main vertical and horizontal structural systems and their peculiar constructive techniques; design code; any strengthening and seismic retrofit interventions, and related risk indicator assessed according to the legislation in force at the time of the design and execution of the work;
- *Section C,* including: data on the use of the US; some geometrical and dimensional features (number of storeys, area floor, etc.); constructive techniques of non-structural elements, such as infills, facade/claddings; information on maintenance/retrofitting interventions if any, for both structural and non-structural element, (e.g. beams, columns, floors, infills, facade/cladding; hydraulic and electrical systems).

Not all the *ARES DB* is included in the PELL-School platform, as the aims of the two platforms are indeed different. PELL-School will acquire only ARES data relevant for the identification of the school building and of its structural units, and for performing their seismic vulnerability assessment as well as their energy efficiency assessment. Any data included in ARES that is judged to be relevant for the aforementioned aims is directly acquired in PELL-School automatically sourcing it from ARES, thus avoiding any replication of data request to the Public Administrations, PAs.

This is possible thanks to the interoperability between *ARES DB* and *PELL-School-RS*, meaning that all the relevant data collected and collated in ARES will be available in PELL-School; after an initial acquisition of the data already included in ARES and relevant to PELL a webservice will be established between ARES and PELL-Schools allowing to periodically check for and to periodically acquire newly uploaded data and/or updated data.

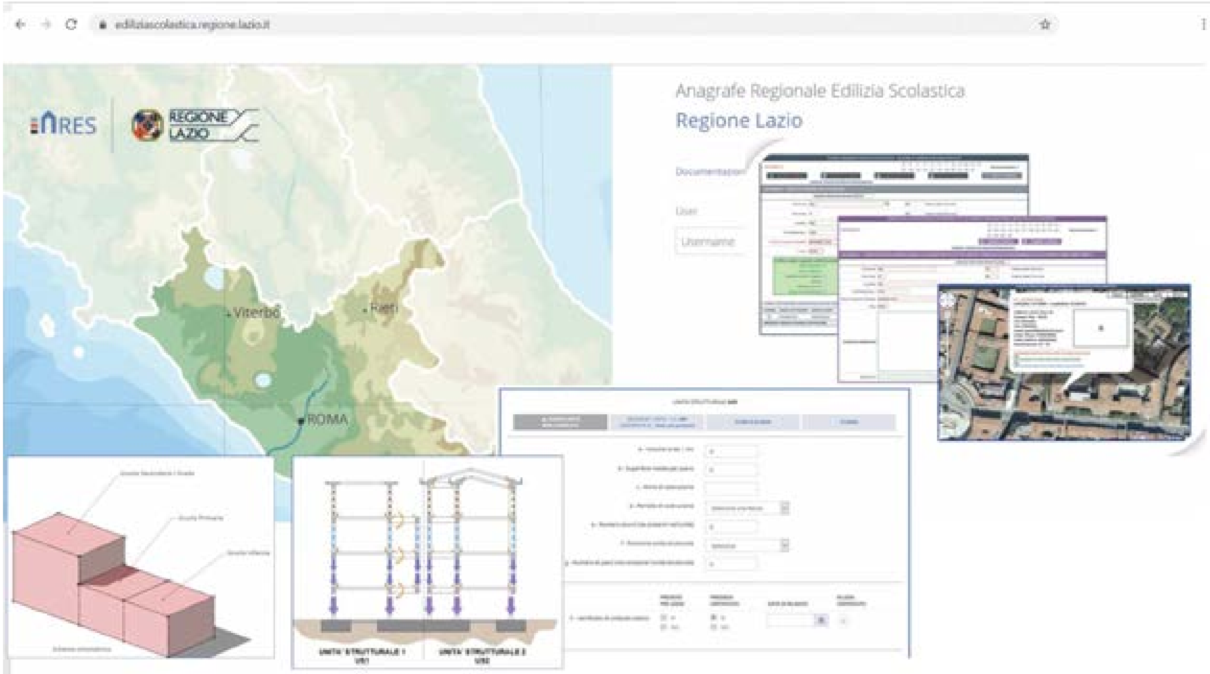


Figure 3. ARES Platform: Layout of the dashboard and GUI interfaces and pictures from ARES manual that clarifies the concept of PES and of US, Structural Unit.

PELL-School replicates in its data structure (Figure 2) the two seismic vulnerability assessment forms established by OPCM n. 3274 2003 [1], namely: *PdCM Level 0 Form*, and *PdCM Level 1-2 Form*. *PdCM Level 0 Form* aimed to support a first-step screening of the structures whose seismic vulnerability should have been assessed according to OPCM n. 3274 and to support a prioritization for their thorough seismic vulnerability assessment and identification of any required seismic retrofit intervention. Several data requested by *PdCM Level 0 Form* are already included in the ARES DB, namely: identifying data, geometrical data, construction period, material of the main vertical structural system, use of the building and presence of retrofitting interventions.

*PdCM Level 1-2 Form,* collect the necessary information to perform an engineering assessment of the seismic vulnerability, according to the codified methodology in the current Italian seismic code, NTC 2018 [8], to assess the a Risk Indicators (α), defined as US Capacity vs. Demand ratios; a brief summary on the concept underpinning the assessment of the seismic Capacity for US in terms of its performance at the various Limit States, according to [8], is provided in section 4.1. *PdCM Level 1-2* Form includes 30 different sections where data are collected either as unique or multiple choice questions or by fill-in boxes where written or numerical information have to be provided, as appropriate. Data included in *PdCM Level 1-2* Form have been replicated in the *PELL-School RS* module, as follow: sections from 1 to 20 and section from 29 to 30 have been replicated and expanded (as briefly mentioned in the following); sections from 21 to 28 included have been grouped in the field 11 of the *PELL-School RS* module (see Figure 2) and faithfully replicated with no proposed addition.

For both *PdCM Level 0* and *Level 1-2* Forms, that were originally conceived in paper format, data digitization is allowed through an ad-hoc software that the Department of Civil Protection, DPC, has prepared and made available to the Italian Regions[4]. Provided DPC approval already digitalized data, available as **.mdb* files will be acquired by the *PELL-School RS* module and interoperability between the DPC repository and *PELL-School* will be established.

Further institutional forms/approaches, that have been taken as a reference and from where some data were sourced for inclusion in the *PELL-School RS* module include: "*Guidelines for the Seismic Risk Classification of Buildings*" so-called "*SismaBonus*" [4] and "*CLE, Limit Condition in Emergency"*[5] form [6].

"*SismaBonus*" approach (Figure 4), that is briefly described in section 4.1, uses EMS-98 [8] typological classification to attribute a typological seismic vulnerability class to a building (Figure 4, step 1) and provides a list of constructive and geometric criticalities/peculiarities (Figure 4, step 2) to be surveyed and accounted for towards refining the assessment. Retracing the macroseimic approach proposed by [7], "*SismaBonus*" approach [4] establishes that a building can be judged to belong to a worse or better seismic vulnerability class, on respect to the one attributed simply by a typological identification, once considered respectively any anti-seismic peculiarities or criticalities that can be recognised in the building.

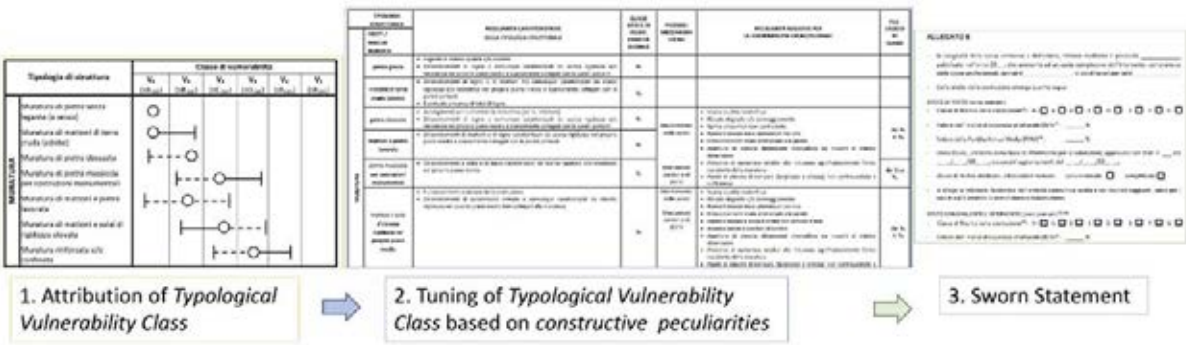


Figure 4. Schematic representation of the simplified *"SismaBonus"* approach for masonry building typologies.

As an example, for the definition of field 5 of the *PELL-School RS* module, namely "*Main structural material of vertical structures*", as far as masonry buildings are concerned, the masonry typologies recognized by "*SismaBonus*" (indeed the same recognized by EMS-98) were integrated in *PELL-School RS* module with the ones considered by the *PdCM Level 1-2* form and with the ones included in the *ARES DB* (Figure 5); as a matter of fact the three aforementioned forms/approaches refer to a different classification system for masonry buildings and *PELL-School* aims to be inclusive and interoperable with them all and avoid data replication as said (Section 1). Furthermore several geometric criticalities/peculiarities (Figure 4, step 2) included in "*SismaBonus*" have been included in the fields from 16 to 18 of the *PELL-School-RS* module (Figure 5).

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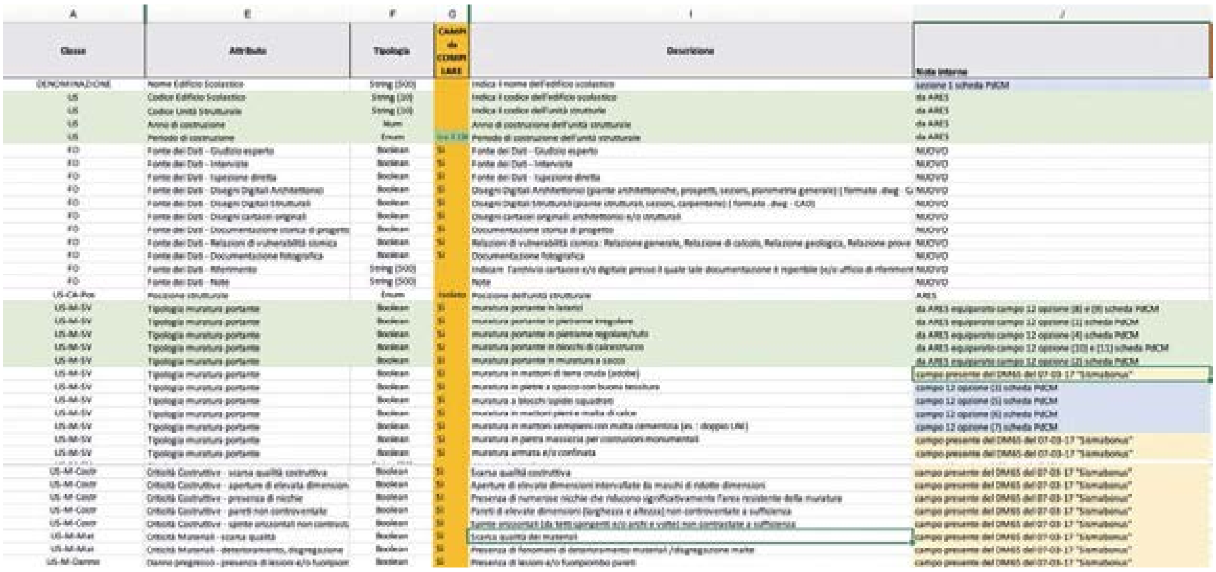
[4] DPC circular /SISM/0092847 of 09/12/2010 rules the digitization *PdCM Level 0 and Level 1-2 Forms* through the software "DPC Liv1-2.msi" prepared by DPC and available at http://www.fileserve.com/file/CUkc9mM

[5] http://www.protezionecivile.gov.it/en/risk-activities/seismic-risk/activities/analysis-limit-condition-emergency



| A | E | F | G | I | J |
|---|---|---|---|---|---|
| Classe | Attributo | Tipologia | CAMPI da COMPILARE | Descrizione | Note interne |
| DENOMINAZIONE | Nome Edificio Scolastico | String (500) | | Indica il nome dell'edificio scolastico | sezione 1 scheda PdCM |
| US | Codice Edificio Scolastico | String (20) | | Indica il codice dell'edificio scolastico | da ARES |
| US | Codice Unità Strutturale | String (20) | | Indica il codice dell'unità strutturale | da ARES |
| US | Anno di costruzione | Num | | Anno di costruzione dell'unità strutturale | da ARES |
| US | Periodo di costruzione | Enum | [illegible] | Periodo di costruzione dell'unità strutturale | da ARES |
| FO | Fonte dei Dati - Giudizio esperto | Boolean | Si | Fonte dei Dati - Giudizio esperto | NUOVO |
| FO | Fonte dei Dati - Intervista | Boolean | Si | Fonte dei Dati - Intervista | NUOVO |
| FO | Fonte dei Dati - Ispezione diretta | Boolean | Si | Fonte dei Dati - Ispezione diretta | NUOVO |
| FO | Fonte dei Dati - Disegni Digitali Architettonici | Boolean | Si | Disegni Digitali Architettonici (piante architettoniche, prospetti, sezioni, planimetria generale) (formato .dwg - C | NUOVO |
| FO | Fonte dei Dati - Disegni Digitali Strutturali | Boolean | Si | Disegni Digitali Strutturali (piante strutturali, sezioni, carpenterie) (formato .dwg - CAD) | NUOVO |
| FO | Fonte dei Dati - Disegni cartacei originali | Boolean | Si | Disegni cartacei originali: architettonici e/o strutturali | NUOVO |
| FO | Fonte dei Dati - Documentazione storica di progetto | Boolean | Si | Documentazione storica di progetto | NUOVO |
| FO | Fonte dei Dati - Relazioni di vulnerabilità sismica | Boolean | Si | Relazioni di vulnerabilità sismica : Relazione generale, Relazione di calcolo, Relazione geologica, Relazione prove | NUOVO |
| FO | Fonte dei Dati - Documentazione fotografica | Boolean | Si | Documentazione fotografica | NUOVO |
| FO | Fonte dei Dati - Riferimento | String (500) | | Indicare l'archivio cartaceo e/o digitale presso il quale tale documentazione è reperibile (e/o ufficio di riferiment | NUOVO |
| FO | Fonte dei Dati - Note | String (500) | | Note | NUOVO |
| US-CA-Pos | Posizione strutturale | Enum | Isolato | Posizione dell'unità strutturale | ARES |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura portante in laterizi | da ARES equiparato campo 12 opzione (8) e (9) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura portante in pietrame irregolare | da ARES equiparato campo 12 opzione (1) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura portante in pietrame regolare/tufo | da ARES equiparato campo 12 opzione (4) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura portante in blocchi di calcestruzzo | da ARES equiparato campo 12 opzione (10) e (11) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura portante in muratura a sacco | da ARES equiparato campo 12 opzione (2) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura in mattoni di terra cruda (adobe) | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura in pietre a spacco con buona tessitura | campo 12 opzione (3) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura a blocchi lapidei squadrati | campo 12 opzione (5) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura in mattoni pieni e malta di calce | campo 12 opzione (6) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura in mattoni semipieni con malta cementizia (es.: doppio UNI) | campo 12 opzione (7) scheda PdCM |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura in pietra massiccia per costruzioni monumentali | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-SV | Tipologia muratura portante | Boolean | Si | muratura armata e/o confinata | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Costr | Criticità Costruttive - scarsa qualità costruttiva | Boolean | Si | Scarsa qualità costruttiva | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Costr | Criticità Costruttive - aperture di elevata dimension | Boolean | Si | Aperture di elevate dimensioni intervallate da maschi di ridotte dimensioni | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Costr | Criticità Costruttive - presenza di nicchie | Boolean | Si | Presenza di numerose nicchie che riducono significativamente l'area resistente della muratura | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Costr | Criticità Costruttive - pareti non controventate | Boolean | Si | Pareti di elevate dimensioni (larghezza e altezza) non controventate a sufficienza | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Costr | Criticità Costruttive - spinte orizzontali non contrastate | Boolean | Si | Spinte orizzontali (da tetti spingenti e/o archi e volte) non contrastate a sufficienza | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Mat | Criticità Materiali - scarsa qualità | Boolean | Si | Scarsa qualità dei materiali | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Mat | Criticità Materiali - deterioramento, disgregazione | Boolean | Si | Presenza di fenomeni di deterioramento materiali / disgregazione malte | campo presente del DM65 del 07-03-17 "Sismabonus" |
| US-M-Danno | Danno pregresso - presenza di lesioni e/o fuoripiom | Boolean | Si | Presenza di lesioni e/o fuoripiombo pareti | campo presente del DM65 del 07-03-17 "Sismabonus" |

Figure 5. Screenshot of some of the data included in *PELL-School RS* for masonry building typologies where in (last column of the table) is clarified the origin of the data field: ARES (green rows); newly proposed (white); Sismabonus (yellow); PdCM (light blue).

As far as the "*CLE, Limit Condition in Emergency*" approach[6] is concerned that included 5 forms (namely: Strategic Building, ES; Emergency Area, AE; Infrastructure Accessibility/Connection, AC; Structural Aggregate, AS; Structural Unit, US), *PELL-School RS* is including in fields from 16 to 18 the *CLE AS Form* data structure that collect relevant data on the possible negative interaction between adjacent US due to, for instance: the misalignment between roofs, slabs or façade walls; the misalignment in interior spaces; juxtaposition or structurally poorly connected elements (such as stairwells, canopies, balconies); incongruous punching system; isolated pillars, arcades, piloty floors; the presence of terraces, towers, chimneys. Data-structure of the further *CLS Forms* will be included in the near future development of *PELL-School-RS* as the aim would be to assess *PELL-School KPI*, not only for the school in itself but also for all the essential structures and services whose functionality are strongly influential, if not vital, for the functioning of the school.

As a matter of fact the final goal of the *PELL-School* should be to collect data and assess KPI towards a continuous monitoring of the school resilience both in business as usual time and in consideration of possible crises event. For the latter point, as far as seismic events are concerned, the idea is to include in *PELL-School* data relevant to all the Disaster Risk Management, DRM, cycle. In Figure 6 are showcased, as an example, forms currently used by the National and Regional Civil Departments and relevant to school buildings as well as to other strategic buildings for the three phases of DRM, namely before, during and after disaster:

a) Before disaster: *PCdM Level 0* and *Level 1-2* forms (already fully included in *PELL-School-RS*) and CLE Forms (partially included in PELL, only CLE AS data at the time being);

[6] The analysis of the CLE of the urban settlement is carried out using standards of storage and cartographic representation of data, collected through a special form prepared by the Technical Commission for the studies of MS, established by OPCM 3907/2010 (art. 5 paragraphs 7 and 8), and issued by a special decree of the Head of the Department of Civil Protection.

b) During disaster: *FAST Form* for the synthetic assessment of post-earthquake usability (all the structural, geometrical and typological data of the FAST form are already included in *PELL-School-RS*; to be included data on the FAST 4 levels usability scale, i.e.: usable; non usable; non usable because of external risks; inspection non performed for causes to be specified.

c) After disaster: *AeDES Form*[7] for post-earthquake damage and safety assessment and short term countermeasures identification; and form used by Region for post-disaster reconstruction reconnaissance as the ones used after 2009 L'Aquila (Italy) earthquake and stored in an ad-hoc created repository, i.e. *School Building Information System* (*in Italian Sistema Informatico Edilizia Scolastico, SIES*) with whom, needleless to say *PELL-School-RS* will try to establish interoperability and data exchange.

AeDES form include 8 sections plus a note section. *PELL-School-RS* includes already data of 4 of those sections related to building identification, description, typology, soil and foundation. Still to be included in *PELL-School-RS* is the *AeDES* data structure related to damage assessment (i.e., damage to main structural components; damage to non-structural elements; external risk and existing short term countermeasures) and usability assessment.

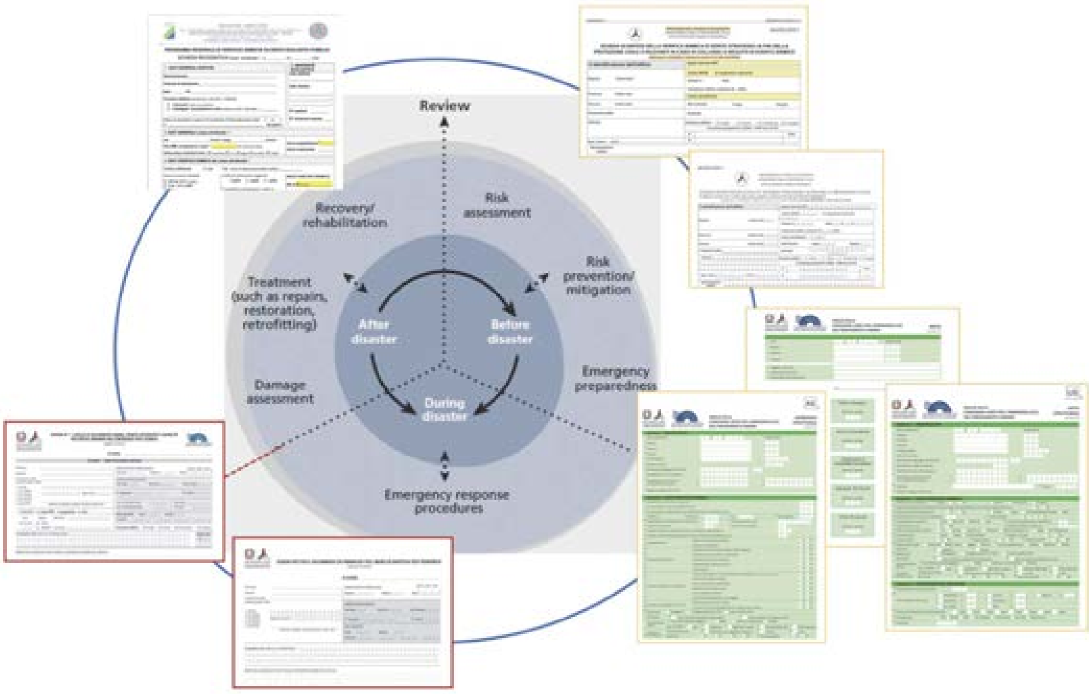



Figure 6. Some of the institutional forms used in Italy in the different phases of the Disaster Risk Management cycle, namely: before disaster PdCM and CLE forms; during disaster FAST form; post disaster AeDES and

It is worth highlighting that:

- more than 50% of the information that are usually collected and collated in post-disaster circumstances with the *FAST Form* and the *AeDES Form* would be already available in *PELL-School-RS;* this will significantly speed up the post-disaster operations of damage and usability assessment;
- *PELL-School-RS* dynamically assessed KPI can support and inform post-disaster operations of damage and usability assessment;
- It is also worth highlighting that on the other hand it will be important to include in *PELL-School-RS* the additional fields comprised in the *FAST Form* and *AeDES Form*, as those

[7] https://core.ac.uk/download/pdf/38619561.pdf

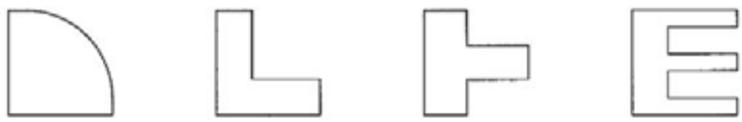
data will be a vital source of information to validate and tune, if necessary, dynamically calculated KPIs.

### 3.2 Newly proposed data

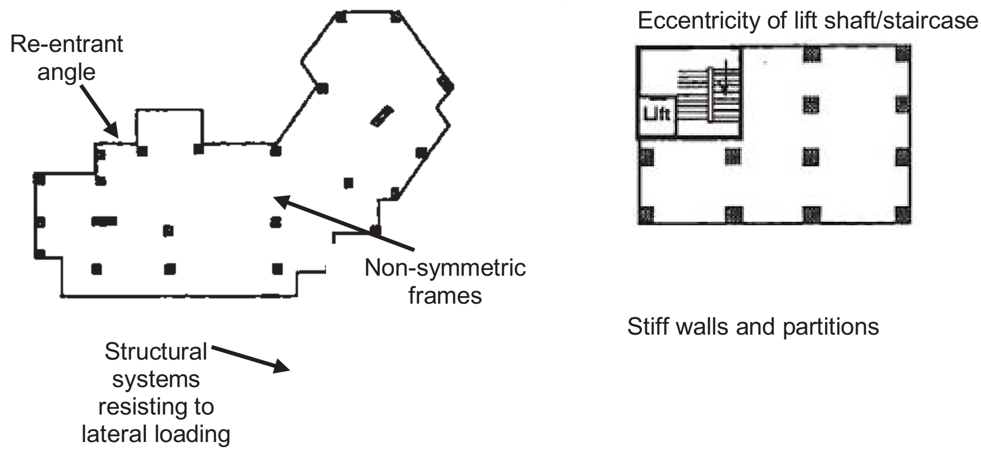
When assessing the earthquake prone status of buildings, initial screenings are needed to identify any weakness in the structure that could potentially influence its capacity, consequently reducing the building seismic performance thereby increasing the life safety risks to occupants and/or having a negative effect on neighbouring buildings. In order to collect key vulnerabilities without going through the length of an extensive analysis, new defined data/information have been proposed and included in *PELL-School-RS.* These data can be easily collected from available architectural and structural drawings (digital files and/or original paper documents), photographic records and technical reports on the building seismic vulnerability.

Focusing on Reinforced Concrete (RC) buildings, general information on the building position (isolated, internal, edge), type of structural system resisting to lateral loads (frame, wall, combination of both) as well as warping and typology of flooring system (e.g. heavy/light) are added to the existing data, as crucial aspects to determine the structural capacity in earthquakes and potential impacts on adjacent buildings. As an example, a brief explanation is provided for the newly proposed data included in the data groups from 16 to 18 (Figure 2), in particular:

*16. Geometric Criticalities:* Data collected here are related to the possible presence of: both plan and vertical irregularities. Plan irregularities might include non-symmetrical plan shapes, e.g. L-, T-, E- (Figure 7a) and non-symmetrical structural systems; large spacing of lateral systems in case of long-narrow buildings; non-uniform and eccentric distribution of weights (as well as ramps, stairs, walls, stiff partitions); the presence of torsional effects in case of corner buildings. Vertical irregularities concern the possible presence of soft stories, mass variation, vertical discontinuity of structural systems (Figure 7b). Moreover, geometrical weaknesses might also include the presence and dimensions of structural gaps (building separation), that can lead to pounding effects.



(a)



(b)

Figure 7. Schematic illustration of: a) plan irregularities; b) vertical irregularities.

17. *Constructive and Material-related Criticalities:* Constructive criticalities for RC building mainly relate to the peculiar plan and vertical distribution of infill walls (that severely interact with the primary structure system during earthquakes, possibly contributing to the increase of both stiffness and strength or to brittle global collapse mechanisms such as soft story mechanisms), the presence of short columns, the absence of measures able to mitigate brittle collapse mechanisms and out-of-plane expulsions. Material-related criticalities for RC buildings refers to: low quality concrete and/or degraded concrete; low quality steel bars, or presence of plain round bars, corrosion. Poor materials and deterioration might lower even considerably the capacity of structural members.

*18 Structural Details critical to the seismic response*: These comprise indications on the detailing of beam-column joints, the steel reinforcement ratios, longitudinal and transverse steel spacing and detailing of structural members, the location of lap splices and anchorage of longitudinal bars, the detailing in the critical dissipative zones, as well as the absence of hierarchy of strengths (capacity design) principles. Structural deficiencies are in fact a consequence of incorrect design methods adopted in the past, based on gravity loading only and not accounting for seismic forces. Therefore, structural details are required as additional data in order to identify possible failure modes of the building structural elements.

In addition to the judgment on each structural weakness, the provision on numerical dimensional data is requested, specifically: the length and number of spans in both structural directions; the section geometry (width, height) and reinforcement quantities (longitudinal, transverse) for beams, columns, walls, the beam-column joint details (w/ or w/o stirrups, type of bar anchorage in the joints); the thickness of the floor slab and its reinforcement details. These quantities allow to estimate the local and global capacity of the building by simple analytical calculations, as briefly explained in the following section.

## 4 PELL-SCHOOL-RS KEY PERFORMANCE INDICATORS, KPI

PELL platform assess both static KPI, providing a measure of the building seismic vulnerability and expected “nominal” risk index through the estimation or evaluation of capacity/demand ratio with reference to a nominal/code design earthquake intensity (Section 4.1), and dynamically computed KPI (Section 4.2) that in the occurrence of a seismic event aim to provide a quasi-real time estimation of the extent of damage occurred and of the expected level of safety and functionality of the school building. This is done through comparison with the engineering demand parameter thresholds associated to various limit states: i.e. Operational (SLO), Damage Control (SLD), Life Safety (SLV) and Collapse Prevention (SLC).

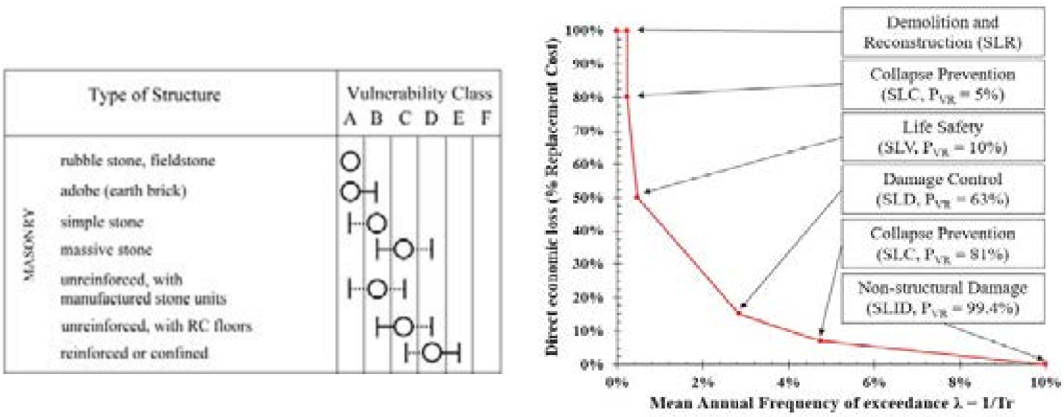
As far as the monitoring of the seismic response is concerned, *PELL-School-RS* conveys continous Key Performance Indicators, as a ratio between the recorded engineering demand parameters, EDP, (actual demand) and the estimated/calculated EDP capacity thresholds associated to the various Limit/Damage States, calculated after the automatic processing of data recorded from MEMS- based accelerometers. The final aim is to derive an objective, prompt and quantitative indication of the damage state and level of safety and functionality of the school building in the aftermath of a seismic event.

### 4.1 Static KPI

As discussed in the previous section, the collection of additional input data in the *PELL-School-RS* aims at identifying the critical weaknesses/vulnerabilities of buildings. Moreover, these data allow to assess the Seismic Risk Class, including both the Safety Index (IS-V, $\zeta_E$)and Expected Annual Losses (EAL) before and after seismic retrofitting interventions. The estimation of these safety and (economic) performance indicators is proposed in the *PELL-School-RS* by adopting the methodology currently adopted in Italy for the classification of the seismic risk of residential buildings [4].

Referring to the official forms provided by the Italian Presidency of the Council of Ministers (PCM), according to the OPCM n. 3274, 2003, namely *Levels 1-2* assessment for strategic structures, Risk Indicators (α) are defined as Capacity vs. Demand ratios in terms of both Peak Ground Acceleration (PGA) - $PGA_C/PGA_D$ - and Return Period ($T_R$) - $T_{RC}/ T_{RD}$ -. The α values are computed at the four different seismic intensity levels or Limit States, namely: Operational (SLO), Damage Control (SLD), Life Safety (SLV) and Collapse Prevention (SLC). The seismic Demand ($PGA_D$, $TR_D$) represents the design demand in acceleration/period for a new building located in the same site. The seismic Capacity in terms of acceleration ($PGA_C$) depends on the building performance at the various Limit States and is evaluated according to the codified methodology in the current Italian seismic code, NTC 2018 [9], considering both brittle and ductile failure modes. On the other hand, the Capacity in terms of Return Period ($T_{RC}$) can be computed from the $PGA_C$ by using the seismic hazard maps provided by the Italian seismic code. It is worth noting that, typically, the seismic hazard curves have a concave shape. Therefore, in order to provide a $T_R$-based risk scale similar to the PGA-based scale and according to the PCM approach, the Return Period ratio ($TR_C/TR_D$) is raised to the power of 0.41 (value obtained from statistics on hazard curves at national level). Referring to these Risk Indicators ($T_R$, PGA ratios), low α values clearly mean high seismic risk, while values of around 1 indicate a safety level comparable to new buildings.

Similarly, in the "*Guidelines for the Seismic Risk Classification of Buildings*", DM 65 2017 [4], a Safety Index (IS-V) of the building is proposed and defined as the Capacity vs Demand ratio in terms of PGA at SLV intensity level (same as the Risk Indicator defined in the PCM).




a) b)

Figure 7. a) Evaluation grid based on the European Macroseismic Scale EMS-98 [8] for masonry buildings (adopted in the simplified method); b) PAM curve as defined in the SismaBonus guidelines [4].

These guidelines, so-called "*Sisma Bonus*", define a general framework to identify the Seismic Risk Class of buildings as well as the rules to access significant financial incentives (from 75% to 110% in the form of tax deductions in 5 years) when implementing seismic retrofitting interventions. The Risk Class can be assessed by two alternative approaches: 1) the so-called "*simplified*" approach, applicable to masonry structures only and based on the qualitative and archetype-based classification provided by the European Macroseismic Scale (EMS-98 [8], Figure 7a); 2) the "*conventional*" approach, based on the quantification of the capacity and demand, through the implementation of the current code provisions, NTC2018 for the estimation of both the Safety Index (IS-V or $\zeta_E$) and the Expected Annual Losses index (EAL, or PAM in the Italian guidelines). In the latter approach, the Seismic Risk Class of the building is defined as the minimum between the two classes associated with the two mentioned indicators (from A+ to F for IS-V, from A+ to G for PAM, where A+ indicates higher performance).

The EAL (or PAM) index is evaluated by assessing the seismic performance in terms of Mean Annual Frequency of exceedance (MAF or $\lambda = 1/T_R$) at different Limit States (SLO, SLD, SLV, SLC, plus SLDI, SLR, i.e. Non-structural Damage, Demolition and Reconstruction, respectively). Then, a direct economic loss, expressed as a percentage of the Reconstruction Cost of the building (%RC), is associated with each Limit State. Hence, the EAL index is defined as the area under the curve obtained by connecting the λ-RC points, as shown in Figure 7b.

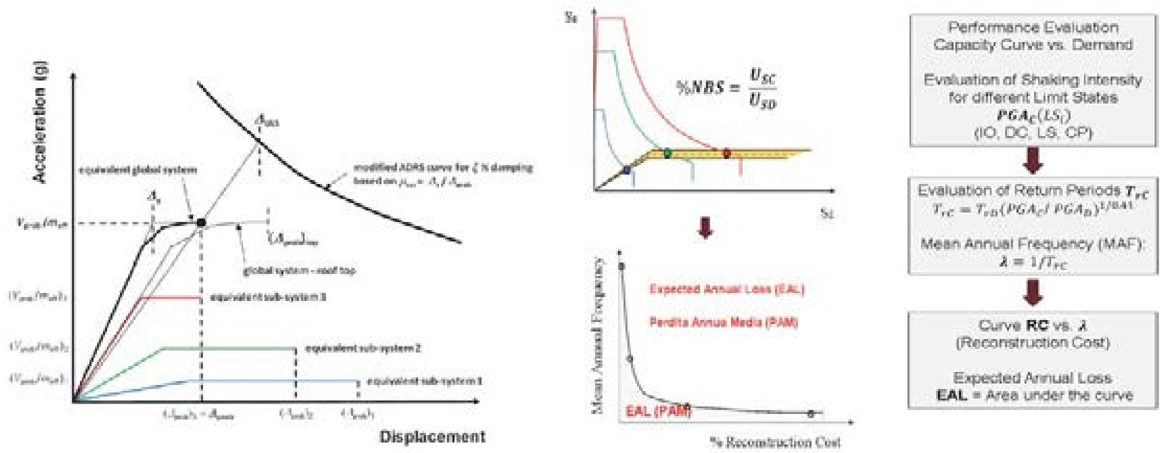



Figure 8. Evaluation of the Safety Index α/IS-V (left) and EAL (right) through the SLaMa Method

The data included in the PELL form allow to compute these key performance indicators (α/IS-V/$\zeta_E$ and EAL/PAM). More specifically, as a further step of this research, the building data can be used to implement a simplified analytical-mechanical seismic assessment of the structure, referred to as SLaMA method (Simple Lateral Analysis Mechanism), developed and introduced in the NZSEE2017 Seismic Assessment Guidelines and fully compatible with, and applicable within, the framework of the Italian NTC2018 code provisions. Following this method, a rapid estimation of the safety level of existing buildings as well as of the expected annual losses can be analytically computed, without any need for a computer/numerical model. In fact, SLaMA allows to determine the force-displacement (pushover) capacity curve and the sequence of local and global mechanisms of a structure by simple analytical (by "hand") calculations. Therefore, SLaMA results can be used to determine the α/IS-V and EAL classes

(Figure 8) according to the state-of-the-art methodologies available for non-linear static analysis (pushover curve, Capacity) in combination with the Demand within a ADRS, Acceleration-Displacement Response Spectrum (i.e., Capacity Spectrum Method, ATC 1996 [10], or N2 method, Fajfar 2000 [11]).

Overall, four levels of vulnerability assessment evaluation are envisaged (Table 1) for the assessment of static KPI, (Tiers Sn, n from 1 to 4) including a vulnerability-index based analysis as a Tier 0S, plus three Tier level based on either static and dynamic analyses, and on either analytical or numerical models, namely:

- *Tier S0*, vulnerability-index based analysis that envisages the attribution of a vulnerability class and vulnerability index, V, according to [4] and [7] respectively to be adopted for screening and prioritization purposes;
- *Tier S1*, dynamic elastic (modal, response spectrum) analysis - numerical model;
- *Tier S2* , a) non-linear static (pushover) analysis - analytical model (SLaMa method), b) non-linear static (pushover) analysis - numerical model (SLaMa method);
- *Tier S3*, non-linear dynamic (time-history) analysis – numerical model.

| | Required information | Demand Parameter | Approach | Risk or damage KPI |
|---|---|---|---|---|
| Tier S0 | *PELL-School RS* Data groups 5, 16, 17, 18 | PGA | Macroseismic Sisma Bonus | V |
| Tier S1 | *PELL-School RS* Static Data (All) | Design Spectra ($T_R$, PGA for SLO, SLD, SLV and SLC level) | Numerical Model | α/IS-V and EAL |
| Tier S2a Non Linear Static Analytical (Simplified) | *PELL-School RS* Static Data (mandatory only)* | Design Spectra ($T_R$, PGA for SLO, SLD, SLV and SLC level) | SLaMA analytical method | α/IS-V and EAL |
| Tier S2b Static Numerical (Conventional) | *PELL-School RS* Static Data (All) | Design Spectra ($T_R$, PGA for SLO, SLD, SLV and SLC level) | Numerical Model | α/IS-V and EAL |
| Tier S3 Dynamic | *PELL-School RS* - Static Data - Dynamically collected data from SHM | Spectrum compatible accelerograms | Numerical Model +SHM | KPI |

*Exclusion made for the Data group 11 (Figure 2), i.e. “Additional data needed for the PdCM Level 1-2 assessment”

Table 1. *PELL-School-RS* Tiered approach for static KPI assessment.

Each approach allows to evaluate, with difference level of trade-off between complexity of the analysis, accuracy, effort/cost and engineering judgement (Figure 9), the expected performance of the school building both in terms of Safety Index and Expected Annual Losses, under various levels of earthquake intensities, i.e. represented by design spectra or spectrum compatible input ground motions (accelerograms).

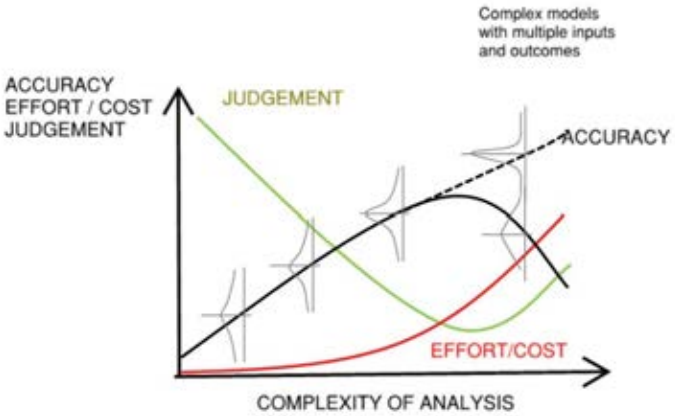



Figure 9. Trade-off and relationship between complexity of the analysis and accuracy, effort/cost, engineering judgement (Kam and Jury, 2015, NZSEE2017)

### 4.2 Dynamically assessed KPIs

The seismic monitoring is of fundamental importance to assess the post-event response, performance and actual EDPs and expected damage and validate/integrate the model prediction with the observed damage and actual response of the instrumented buildings.

Similarly to what proposed for the static KPI, *PELL-School-RS* will follow a tiered approach for dynamically assessing KPIs post-event including two Tiers (Table 2), namely:

- *Tier D1,* Dynamic Simplified analysis - analytical model;
- *Tier D2,* Dynamic Simplified analysis - numerical model.

| | Required information | Demand Parameter | Approach | Risk or damage KPI |
|---|---|---|---|---|
| Tier D1<br>Dynamic Simplified | PELL-Building RS Static Data (mandatory only)*<br>Dynamically collected data from SHM | $T_R$, PGA for SLO, SLD, SLV and SLC Limit States using response Spectra from recorded event accelerogram | SLaMA method +SHM | Limit States KPIs |
| Tier D2<br>Dynamic | PELL-Building RS<br>• Static Data (ALL)<br>• Dynamically collected data from SHM | Recorded accelerogram and actual EDP from SHM monitoring | Numerical Model +SHM | Limit States KPIs |

Table 2: *PELL-School-RS* Post-event Tiered approach for dynamically assessed KPI assessment.

As far as the Tier D2 approach is concerned, the idea is to adopt the procedure set-up by Mori et al. [12] that includes four steps, namely: i) collecting basic data on the foundation soil and on the building; ii) in situ experimental measurements on the foundation soil and on the building; iii) Operational Modal Analysis (OMA) analysis and modeling through the SMAV software; iv) evaluation of the structural and operational performance of the building.

With reference to the data collection (i), the required basic data include the structural and architectural plans, the floor heights, the type of structural elements and the volume mass of materials; all these data are already collected as part of the *PELL-School-RS* module (Figure 2).

As for the experimental measures (ii), polygons with rigid behavior are identified within each floor of the building, and sensors are deployed at all the building floors and at least at two locations within each polygon using, if possible, the same configuration for all the floors.

As for the OMA (iii) the SMAV software is used: the translational and rotational mass of each identified polygon is considered concentrated in its center of gravity), the participation coefficients and the modal masses are calculated starting from the mass matrix and the experimental deformations defined in terms of translations and rotations of the polygons. From the identified frequencies and modal shapes for each configuration, and after a suitable check for their independency, the global modal shapes of the entire building are obtained.

As for the evaluation of the structural and operational performance of the building (iv) the SMAV software implements the "frequency drop-drift" literature curves and updates the natural frequencies identified with the OMA by means of an iterative algorithm, which recalculates accelerations, displacements and inter-story drift up to convergence. This equivalent linear dynamic analysis allows to follow the variation of natural frequencies up to the drift thresholds which represent the beginning of the structural damage, including in this damage also the non-structural elements interacting with the structure.

## 5 CONCLUSIONS

This paper presents the on-going activities for the development of the *PELL-School* platform. With the *PELL-School* platform ENEA aims to introduce a shared minimum standard of building knowledge among stakeholders, governance, municipalities and all the involved operators in order to reach a national knowledge and updated evaluation of a very important strategic infrastructure and patrimony, which includes approximately 45.000 public schools in Italy.

In order to test, tune and modify, if necessary, the proposed *PELL-School Seismic-Response* module and to contribute to its implementation on Italian school buildings a Working Group has been set up. The *PELL-School Seismic-Response* Working Group led by ENEA is involving several Municipalities and stakeholders to share and promote the test of the *PELL-School-RS* form (Figure 5) and to contribute to its implementation. The process is also engaging Italian Regions who are in charge of the ARES platform.

Thanks to Municipalities and stakeholders who first joined the Working Group, it has been possible to discuss and test the proposed form on different public schools and so doing, to customize it to the different building peculiarities and to the application capability of the operators. Following the test phase, the *PELL-School-RS* form will be digitized following AgID specifications for data models and will be embedded in the PELL platform, which should be ready by the end of 2022.

Although significant effort have been dedicated by the authors to ensure that the data and KPIs proposed for inclusion in the *PELL-School Seismic-Response* module are aligned and best represent the scientific and professional advancements in the fields of seismic engineering, seismic vulnerability assessment and seismic monitoring of buildings in Italy, that Italy can boast thanks to the work of professional associations, universities, networks of laboratories, research institutions and research foundations, the collaboration of such experts in the Working Group would be welcome and much appreciated.

All the interest experts are therefore warmly invited to take part in the activities of the *PELL-School Seismic-Response Working Group* towards the common goal of guarantying in the short run the seismic safety of schools and other strategic buildings in Italy.

*PELL Schools*, is a further step towards the digitization and automation of the information, management and evaluation processes of the strategic infrastructure aiming to renovate streets, districts, towns and territories in order to make them more sustainable, resilient and sharply managed.

ENEA's goal is to make available the *PELL-School* by 2023 for operational use by municipalities and stakeholders.

## ACKNOWLEDGEMENTS

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