16TH EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING THESSALONIKI 18 - 21 JUNE 2018

APPLICABILITY OF THE SUSTAINABLE STRUCTURAL DESIGN (SSD) METHOD AT URBAN/REGIONAL/NATIONAL LEVEL

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ABSTRACT

The present study moves from the awareness about the structural condition of the European building stock, which, in some cases, is far from the level of structural safety required by the European codes. Where the seismic risk is more relevant, as in southern Europe, the adaptation of building heritage according to modern seismic standards must be pursued with an emphasis on sustainability, so that available resources are used as efficiently as possible.

The proposed methodology is the territorial implementation of a building design approach, called Sustainable Structural Design (SSD) Method. SSD is an efficient and solid method aiming at guiding the sustainable construction sector toward a multi-performance and life cycle-oriented approach, including the environmental aspects related to energy consumption and CO_2 emissions, in structural design, performed with a simplified Performance Based Assessment (sPBA) methodology, in order to obtain a global assessment parameter expressed in monetary terms. A simply applicable methodology, allowing the identification of the territorial areas which need a more urgent intervention, is obtained.

Starting from the SSD Methodology, the authors have studied its applicability at territorial level, considering three different area dimensions, as countries, regions and cities, and identifying the most suitable approach for each of them. The application of the SSD at territorial level could allow the main aspects of sustainability to be included, identifying the areas where an intervention could reduce the energy consumptions, the CO_2 emissions and the structural losses of buildings, thus supporting the strategic decision-making on territory.

Keywords: Sustainable Structural Design; simplified Performance Based Assessment; Life Cycle Assessment.

1. INTRODUCTION

Sustainable development is one of the most relevant topics of the last decades. It involves each branch of human activities, from agricultural to safety management areas. The construction sector provides high contributions to the three dimensions of sustainability. Indeed, according to the *social* dimension, a healthy environment has to be guaranteed, since people spend most of their time in buildings; moreover, according to Eurostat data (European Commission 2017a, European Commission 2016), construction sector provides a high contribution to the employment. Considering the *economic* dimension, EU-28's construction sector was made up of more than 3.2 million enterprises in 2013, generating EUR 487 billion of value added (European Commission 2017a). Finally, considering the *environmental* dimension, buildings are responsible for approximately the 40% of the total energy consumption and the 36% of the total greenhouse gases in Europe (European Commission (2013)).
Among the three dimensions, in the last years more attention has been given to the environmental

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issue. EU Commission has revealed that more than 50% of building energy consumption and at least 80% of carbon dioxide emissions can be reduced by taking suitable measures (European Commission (2013)). In order to achieve these results, several global agreements have been signed, from the Kyoto Protocol in 1997, till the Paris Agreement in 2015, which fixed the global commitment in the reduction of climate change, by, among the others, pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. In order to follow the ways indicated by the Agreements, several European Regulations have been published, such as the Directive of the Energy Performance of the Buildings (EU, 2010).
The growing interest in achieving the environmental efficiency of buildings has prevailed, somehow, on an important aspect of the buildings performance: the structural safety. In some cases (Figure 1), this attitude has caused the annulment of the energy benefits and the stultification of the investment plans.

Figure 1. Safety neglect in buildings with energy improvements - Emilia Region earthquake, 2012

The necessity of focusing the attention on structural performances of buildings is clear if statistics on construction age of European building stock are considered. According to Economidou et al. (2011), around 40% of European residential buildings have been built before 1960, when seismic codes had not been developed yet, or did not consider the effective seismic action.
For these reasons, it is clear that a combined approach for evaluating the performances of buildings is necessary for including both the energy and the safety characteristics of the buildings themselves, to create and maintain a sustainable building stock and to optimize the initial investments.
In order to combine the environmental and the safety performances of buildings, the Sustainable Structural Design (SSD) method has been developed by Romano et al (2014). The aim of the method is to equip the buildings with a single parameter, provided in economic terms, which includes energy consumption, equivalent CO_2 emissions and the structural costs.
This methodology has been developed for single buildings. Nevertheless, it is interesting to enlarge the applicability field from building to territorial level in order to give the stakeholders a procedure for the identification of the areas where an environmental and structural intervention is more urgent and would be more efficient.
Firstly, a brief overview of the SSD methodology at building level is provided; then the applicability of the method at urban/regional/national level is reported.

2. SSD METHODOLOGY AT BUILDING LEVEL

The Sustainable Structural Design (SSD) is a methodology aiming at supporting the general design process of buildings. It was developed by Romano et al. (2014), improved by Tsimplokoukou et al. (2014) and applied to a case study by Loli et al (2016). The methodology, outlined in Figure 2, is based on three main pillars, each of them corresponding to a procedure evaluation step: the Energy Performance Assessment; the Life-Cycle Assessment and the Structural Performance Assessment. The fourth step represents the conversion of the three identified pillars in economic terms, to address the so-called “Global Assessment Parameter”.

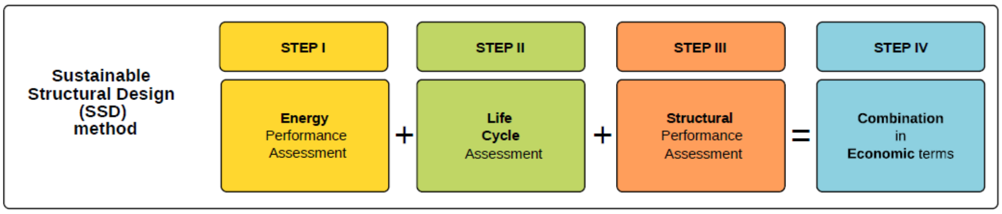

Figure 2. Framework of the Sustainable Structural Design (SSD) Methodology

2.1 Step I: Energy Performance Assessment

The energy performance assessment step is formally part of the Life-Cycle assessment step, but it is performed separately from the latter in order to easily address the operational costs of the buildings. Considering the building life-cycle, the total energy consumption can be evaluated as:

$$E_{LC} = E_E + E_O + E_D \tag{1}$$

where E_{LC} is the life-cycle energy incurred in all phases of the building life; E_E (embodied energy) is the energy required for extracting, manufacturing and transporting the building materials and the energy required for the construction of the building; E_O is the operating energy, including the energy required for space heating, space cooling, water heating, illuminating, running appliances and other end-uses, which is expressed as the product of the annual operating energy and the life span of the building; E_D is the demolition energy, which is the sum of the energy required for the demolition of the building, and the energy referred to the transportation of debris and other building materials to the landfill or recycling plants.
In this phase, only E_O is evaluated because it is interesting to separate this value from the others since (a) European policies are moving towards the reduction of the energy consumptions, reaching the goal of the diffusion of nearly zero energy buildings; (b) the energy prices can include energy taxes related to the carbon content, so having this value separately means to avoid the double inclusion of CO_2 contribution.

2.2 Step II: Life-Cycle Assessment

Life-Cycle Assessment (LCA) is a methodology aiming at the evaluation of the environmental impacts of products and processes generated during their entire life cycle. LCA procedures are regulated by the International Organization for Standards (ISO) ISO 14040:2006. According to it, LCA is addressed by following four steps: the *Goal&Scope* definition, the *Inventory Analysis*; the *Impact Assessment* and the *Interpretation*. It is important to notice that in the Goal&Scope definition phase the system boundary of the LCA study has to be set. To this aim, the EN 15978:2011 provides life-cycle stages and system boundary for buildings.

2.3 Step III: Structural Performance Assessment

The third step of the SSD methodology regards the assessment of the structural performance of the buildings. After the earthquakes of Northridge (1994) and Kobe (1995), the knowledges in building sector have been re-examined, leading to the update of the national technical codes for addressing the structural design with a Performance-Based approach, which is mainly based on the identification of performance levels (limit states).
The first implementation of it has been made for the earthquake events, with the introduction of the Performance Based Earthquake Engineering (PBEE), consisting in the evaluation of the earthquake losses by means of a triple integral. A simplified approach to the PBEE has been proposed by Negro and Mola (2015), which consists in four phases. In phase 1, the limit states are defined (e.g., low damage, heavy damage, severe damage and loss of the building/collapse) and the expected costs related to each limit state are evaluated. The structural damage is evaluated in terms of the inter-storey

drift (IDR). In phase 2, the evaluation of the peak ground accelerations (PGAs) causing the IDR values defined at the previous step is performed, through skeleton curves obtained from IDA or from pushover analysis. In phase 3, the PGAs provided by the previous step are converted in probability of exceedance, by using the return periods provided for each PGA by national codes and the following expression:

$$R_n = 1 - (1 - 1/T_R)^n \quad (2)$$

where R_n is the probability of exceedance in n years and T_R is the corresponding return period.

In phase 4, the economic losses are evaluated summing the product of the probability of exceedance and repair/replacement costs (including downtime costs and any relevant loss), at each limit state:

$$L = \Sigma_{i=1} [C_i \cdot (R_i - R_{i-1})] \quad (3)$$

Finally, the total cost for structural performance assessment is evaluated with the following expression:

$$C_{TOT} = I + L \quad (4)$$

where I is the initial construction cost for the building.

2.4 Step IV: Global Assessment Parameter of the SSD Methodology

The first three steps of the SSD methodology lead to the estimation of different quantities, having different units of measure: kWh or m^3 of gas for the energy (step I), $kgCO_{2,eq}$ for the equivalent environmental impacts (step II) and € for structural costs (step III). The last step of the methodology aims at unifying the building performance outputs in order to provide a unique sustainability value in monetary unit, called "global assessment parameter", R_{SSD}. The conversion of the energy outputs in monetary unit, resulting in the R_E^{Energy} parameter, can be achieved by using the data provided by Eurostat (European Commission (2017b)) for each Member State and for households and industrial consumptions, as the product of the amount of energy consumption (Q^{Energy}) and the energy price (P^{Energy}). The conversion of the environmental impacts, evaluated as mass of equivalent carbon dioxide, in monetary unit can be addressed by means of the information given by the European Union Emission Trading System (EU ETS, 2017), that means that the resulting R_E^{CO2} parameter can be evaluated as the product of the amount of the equivalent CO_2 (Q^{CO2}) and the carbon dioxide price (P^{CO2}), monthly estimated according to a procedure developed by EU ETS. Then, the global assessment parameter, R_{SSD}, can be evaluated with the following expression:

$$R_{SSD} = R_E^{Energy} + R_E^{CO2} + C_{TOT} \quad (5)$$

3. SSD METHODOLOGY AT NATIONAL/REGIONAL/URBAN LEVEL

An important development of the SSD methodology is the application of it at territorial level. If the methodology was applied to small areas, like districts, cities or regions, or to big areas, like nations, it could represent a solid method for supporting the administrations in addressing the policy projects on the territory. Indeed, if the building stock is classified into groups of buildings having similar characteristics and the global assessment parameter is evaluated for each building group, the territory can be divided into areas having same R_{SSD} range, and, according to this classification, areas with highest values of R_{SSD} will result as the ones where a structural and energy intervention is more necessary.

In order to reach the described aims, the development of the SSD methodology at territorial level is briefly summarized in Figure 3. As shown in the figure, Step I represents the energy performance assessment step. The energy performance parameter can be obtained following two different procedures:

- Procedure A, for evaluations at national level
- Procedure B, for evaluation at regional and urban levels, which can be divided into two sub-procedures: B1, where the energy consumption is provided by the European energy databases; B2, where the energy consumption is provided by the Energy Performance Certificates.

Step II represents the life-cycle assessment (LCA) step. The LCA performance parameter is evaluated by using the same procedure for national, regional and urban levels.

Step III represents the structural assessment step. The structural assessment parameter is evaluated by using the same procedure for national, regional and urban levels. The third step consists in an initial phase of building data gathering and stock classification, followed by the loss assessment and the initial costs evaluation.

The conversion of the single parameters in economic terms is performed at the end of each step, so that Step IV simply consists in the sum of them. Each step of the methodology is described in detail hereafter.

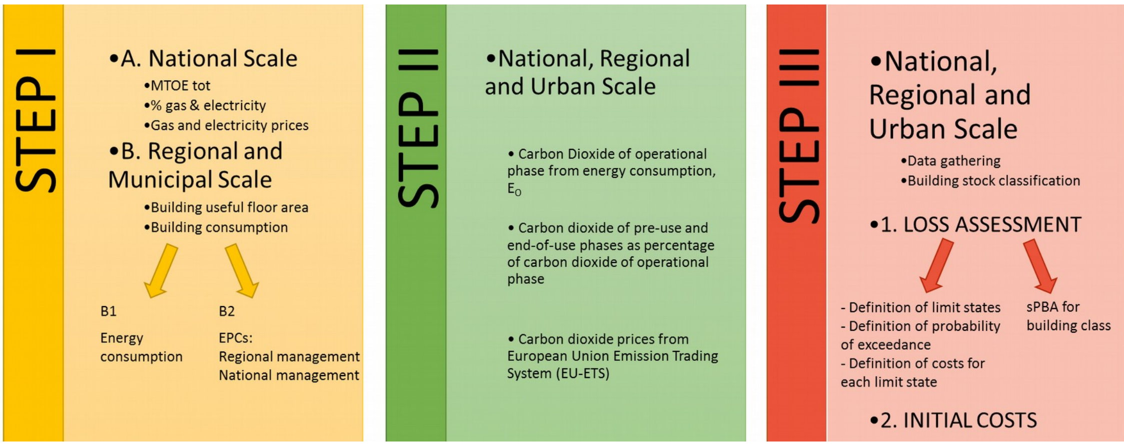

Figure 3: Framework of the development of the SSD methodology at national/regional/urban level

3.1 Step I - Energy performance

3.1.1 Step I.A - Energy performance at national level

In order to provide information on energy consumptions of buildings at national scale, the support of the well-known European databases is required. To select the most robust data, a comparison has been made among the following databases: Eurostat, IEA (International Energy Agency), BPIE (Buildings Performance Institute Europe), ODYSSEE, IVL (Swedish Environmental Research Institute). This comparison has been carried out by considering the energy consumption of household space heating, since, according to ODYSSEE, at the EU level, about two thirds of the consumption of buildings is for residential buildings and, according to IEA and Eurostat, heating covers more than the 50% of the total energy amount. A first comparison on household total energy consumption for all end-uses among the abovementioned databases is shown in Figure 4 for 2011, setting Eurostat as benchmark. According to this, the maximum difference between the databases is equal to 13%. After performing an error analysis, it turned out that IEA has the lowest error (1.36%); this is reasonable because IEA and Eurostat are based upon the same data source. On the other hand, BPIE provides the highest error (5.28%). Finally, ODYSSEE weighted error is equal to 2.67%.

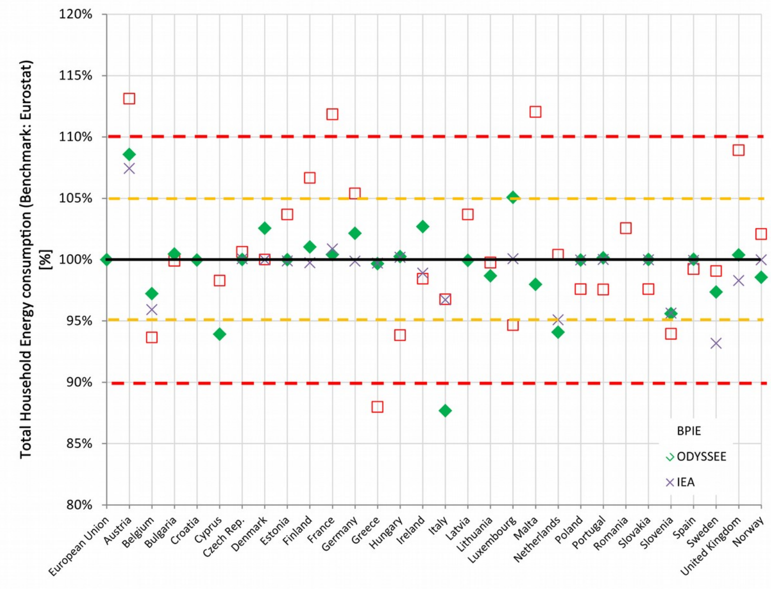

Figure 4: Comparisons among the analyzed databases (Benchmark: Eurostat)

Compared to other energy end-uses, space heating can better address the envelope performance of buildings, since heating is a consequence of construction and building design, more than of users' energetic needs and behaviour. For this reason, starting from Eurostat data sources (European Commission (2017c)) about the total energy consumption of households, classified for each end-use and available for some Member States, a conversion from total energy consumption for all end-uses to total energy consumption for space heating was carried out, by firstly dividing the Member States (MSs) into three geographical areas (North, Centre, South), and then identifying the referred space heating rate (0.65, 0.60, 0.30 respectively). With the help of the space heating rate, the space heating energy consumption has been evaluated for all the EU28+Norway countries, and compared for Eurostat, IEA, ODYSSEE and BPIE databases.
Once the building energy consumptions are evaluated, the consumptions have to be converted into costs. Eurostat provides only electricity and gas prices for each MS. For this reason, starting from these data, yearly national consumption costs for space heating can be evaluated as follows:

$$R_E^{Energy} = \sum_{(i=1)}^{N} \sum_{(j=1)}^{M} (\%_i \cdot (kWh_{TOT,i}/\ year)_{MS} \cdot (€/kWh)_i\ )_j \quad (6)$$

being *i* the *i*-th component of the energy (gas, electricity); *j* the *j*-th building occupancy class (as households, offices, schools,…); *N* the number of energy component considered; *M* the number of building occupancy class considered; *%i* the percentage of the *i*-th energy component on the total, for the considered MS; $(kWh_{TOT,i}/(year))_{MS}$ the annual total energy consumption of the *i*-th energy component, referred to the considered MS; $(€/kWh)_i$ the price of the *i*-th component.

3.1.2 Step I.B - Energy performance at regional/urban level

The option B for the energy performance assessment regards the buildings at regional and urban levels. In option B1, the same data source of option A is used; in option B2, Energy Performance Certificates (EPCs) data source is used. For both the options, information about the buildings floor area is required. For this reason, a comparison about buildings floor area data provided by different databases has been performed. Among the considered databases, data on buildings floor area are provided by BPIE and IVL; moreover, they can be derived from ODYSSEE data regarding energy consumption per square meters (ODYSSEE 1) and average usable floor area per dwelling (ODYSSEE 2). Considering BPIE as benchmark, Figure 5 reveals that usable floor area data do not match well for all the Member States.

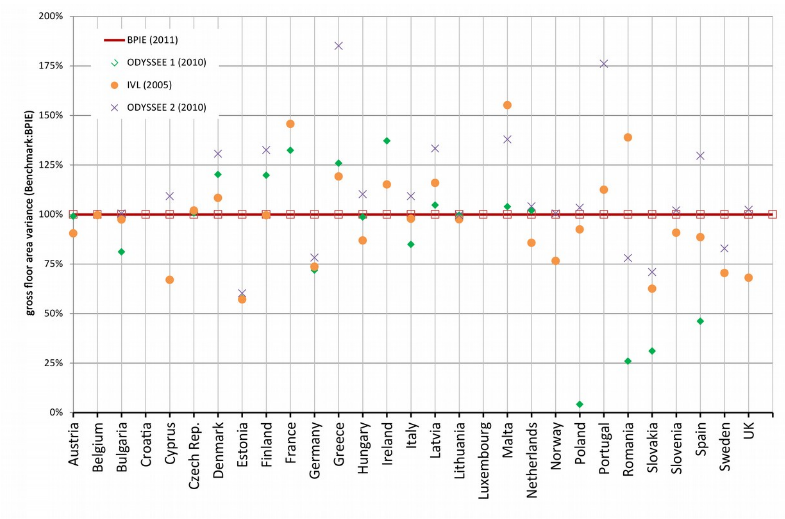

Figure 5: Usable floor area comparison (Benchmark: BPIE)

Data on usable floor area have been used for realizing a comparison among the energy consumptions/m^2. BPIE and ODYSSEE databases provide values in kWh/m^2, while for Eurostat and IEA databases, these values have been evaluated by using BPIE and ODYSSEE 2 usable floor area data. Results, shown in Figure 6, underline that more precise data on space heating energy consumptions per square meter for European Member States are highly necessary.

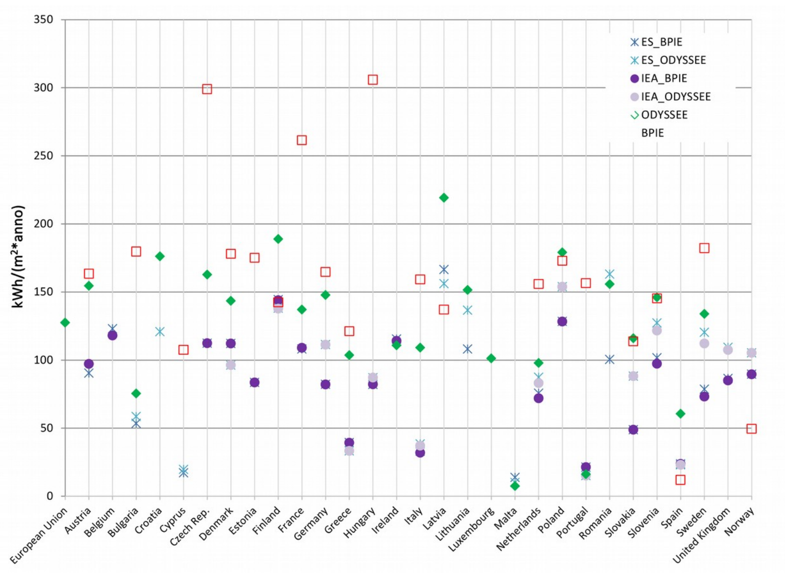

Figure 6: Comparisons among energy consumption/m^2 referred to ES_BPIE, ES_ODYSSEE, IEA_BPIE, IEA_ODYSSEE, ODYSSEE and BPIE

In option B2, energy data are provided by the energy performance certificates (EPCs), normed by the Directive 2010/31/EU, adopted by all the MS. Nevertheless, the commitment in managing the EPCs is given to the Regional or National Institutes, according to what decided in each MS. The methodology for addressing the energy costs according to option B2 is explained considering the case study of Italy, which adopted a Regional management. Some of the Italian regions, e.g. Lombardia, Valle D'Aosta and Sicilia, provide quantitative information regarding the so-called "global non-renewable energy performance index, $EP_{gl,nren}$", expressed in kWh/(m^2 year). Moreover, Lombardia region provides also the total usable area of residential and non-residential buildings, which is an essential data to address the energy performance assessment.

Summarizing, yearly energy performance at regional/urban level can be obtained with the Equation 7 according to approach B1 and Equation 8 according to approach B2:

$$R_E^{Energy} = \sum_{(i=1)}^{N} \sum_{(j=1)}^{M} \left(\%_i \cdot (kWh_{TOT,i}/(m^2 \cdot year))_{MS} \cdot m^2_{(region/city)} \cdot (€/kWh)_i \right)_j \quad (7)$$

$$R_E^{Energy} = \sum_{(i=1)}^{N} \sum_{(j=1)}^{M} \left(\%_i \cdot EP_{gl} \cdot m^2_{(region/city)} \cdot (€/kWh)_i \right)_j \quad (8)$$

where *i, j, N, M, %i* and $(€/kWh)_i$ assume the same significance of Equation 6. Moreover, $(kWh_{TOT,i}/(m^2 \cdot year))_{MS}$ is the annual total energy consumption per square meter of the *i*-th energy component, referred to the considered MS; EP_{gl} is the annual total energy consumption/m^2 of the *i*-th energy component, referred to the considered region/city; $m^2_{(region/city)}$ is the usable area of building groups in the considered region or city.

3.2 Step II - Life-Cycle Assessment

The second step of the SSD methodology aims at evaluating the total carbon dioxide emissions of the buildings at territorial level. In order to realize a correct life-cycle analysis of buildings, computation on materials, processes and transportation would be required. For the purposes of this paper, a simplified approach to the evaluation of the CO_2 emission is used, in which the emissions from the operational phase (CO_2^O) are obtaining by running in the LCA tools the amount of energy consumed during the building lifespan and the contributions of the pre-use (CO_2^E) and end-of-life (CO_2^D) phases are evaluated as percentage of the use phase, being the latter the most CO_2 consuming phase (Sharma et al. (2011))

$$CO_2^{LC}=CO_2^E+CO_2^O+CO_2^D \quad (9)$$

$$E_O \rightarrow CO_2^O \quad (10)$$

$$CO_2^E = a \cdot CO_2^O \quad (11)$$

$$CO_2^D = b \cdot CO_2^O \quad (12)$$

where the coefficients *a* and *b* are set equal to 0.15 and 0.03, respectively, starting from the results provided by Scheuer et al. (2003), Adalberth et al. (2001) and Loli et al. (2016).
The conversion of the equivalent CO_2 emissions into costs is made with the help of the carbon dioxide price (hereafter called P^{CO2}) provided by the EU ETS system, which derives from international policies aiming at charging those who emit carbon dioxide. In November 2017, P^{CO2} was equal to 7,62 €/tCO_2.
Once the equivalent amount of carbon dioxide generated by all the life cycle phases of the buildings $Q_{(CO2)}$ is obtained, the cost of the environmental impact of global change, $R_{E(CO2)}$, can be evaluated as:

$$R_E^{CO2} = Q^{CO2} \cdot P^{CO2} \quad (13)$$

3.3 Step III - Safety performance

Safety performance of buildings can be assessed by evaluating the expected losses generated by events that can occur during the building's lifespan. The evaluation of the building safety performance at territorial scale implies the economic loss estimation of a large number of buildings, which, according to the area size and location, can show different features regarding the building characteristics themselves and the hazards they are exposed to. The present paper focuses on the earthquake loss assessment since the methodologies regarding the seismic performances of buildings are the most solid and studied so far. Starting from the 1970s, earthquake loss estimation methodologies at territorial level have become more rigorous and several earthquake loss assessment software became available. On the wave of the development of methodologies for earthquake loss assessment, the sPBA methodology represents a simplified method that can be applied at territorial level as described soon after. Before developing the steps for the estimation of earthquake losses, two initial phases have to be developed: the collection of data referred to the buildings exposed to the considered hazards and the classification of the buildings themselves into groups having similar structural and non-structural characteristics.

3.3.1 Data gathering

In order to apply the Sustainable Structural Design (SSD) at territorial scale, the existing building stock exposed to natural hazards and environmental risks has to be analyzed. Several techniques for data gathering are available: remote sensing systems, census survey and field survey, having increasing accuracy and resource-consumption. In Italy, an ongoing field survey of all the existing buildings, the CARTIS Project, founded by Italian Civil Protection, (Presidenza del Consiglio dei Ministri (2014)) is collecting all the relevant building characteristics at Municipality level. The project aims at investigating the national building stock for the identification of local construction characteristics. CARTIS survey is carried out by means of a CARTIS form, which is divided into four sections: Section 0, for the Municipal and Compartment identification; Section 1, for the typological identification of each considered Compartment; Section 2, for the identification of the generic characteristics of the Compartment typology; Section 3, for the structural characterization of the buildings.

3.3.2 Building stock classification

When the building stock information is gathered, the building groups having similar characteristics, that means they will very likely show similar damages/losses, have to be tagged with a territorially homogeneous label. Many building stock classifications have been developed in relatively recent years: EMS98 (Gruenthal, 1998), Jaiswal and Wald (2008), RISK-UE classification (Mourouxand Le Brun, 2006), HAZUS classification (FEMA, 1992), Giovinazzi (2005), and others.
Building stock taxonomy defined for the SYNER-G Project (Hancilar et al., 2013), a European collaborative research project funded by European Commission (7^{th} Framework Program), is ideal for the SSD methodology because it allows more information to better model the building stock to be collected. According to SYNER-G taxonomy, the building typology can be defined using the label put in the brackets for each parameter within a given category and following the order of the categories and classifications. For example, a building can be labeled as MRF/C-RC/X/X/RI-FB-H%/ND/R-RC/X/L-2/NC; which means this building is a moment resisting frame (MRF), in reinforced concrete (C-RC) with regular external infill panels in brick with a high percentages of voids (RI-FB-H%), with non-ductile design details (ND), with rigid reinforced concrete floor (R-RC), low-rise, 2 storeys (L-2), not designed to a seismic code (NC). This taxonomy permits other categories and sub-categories to be easily added, in order to take into account all the different kinds of European buildings.
Starting from a CARTIS-like field survey, the buildings can be classified according to the SYNER-G taxonomy. Once the building stock assessment is performed and the exposed buildings are classified into groups having similar characteristics, the evaluation of the expected losses can be achieved for each building group.

3.3.3 Expected earthquake losses evaluation

Expected earthquake losses evaluation is performed by following five steps: definition of limit states, definition of probability of exceedance, estimation of repair/replacement costs, estimation of expected losses for each limit state and estimation of total losses. The evaluation of the structural performance of buildings is necessary linked to the definition of the limit states. Four limit states (LS) are introduced for describing the building performances related to seismic actions: LS1 corresponds to slight damage of the building; LS2 to damage at non-structural elements; LS3 to heavy damage (serious damages and collapse of the non-structural elements and significant damages to structural elements); LS4 corresponds to near collapse (serious damages and collapse of the non-structural elements and very serious damages to structural elements). After defining the limit states, the probability that an event causing the over-mentioned damages for each limit state occurs during the building reference period has to be assessed. The probability of exceedance for each limit state can be

derived by national technical codes. Considering the Italian Technical Code for Structures (2009), the probabilities of exceedance during building reference period (P_{VR}) equal to: 81% for Operability Limit State; 63% for Damage Limit State; 10% for Life Safety Limit State and 5% for Collapse Limit State.
The evaluation of repair/replacement costs after an earthquake is an ongoing research topic. Several approaches have been developed so far; among the others, one could mention: (a) the assessment based on surveys on existing post-earthquake costs data and (b) the analytical assessment according to the sPBA procedure, described by Negro and Mola (2015).
An example of the costs evaluation according to the approach (a) is herein presented. The example is based on the data gathered after L'Aquila earthquake, occurred in Italy in 2009, by the emergency chain ReLuis-CINEAS-FINTECNA, published in the "Libro Bianco" (Bertani et al. (2015)). The book presents the costs related to the rehabilitation of 2245 Reinforced Concrete buildings and 1256 Masonry buildings, classified according to the usability classes, defined by the usability form, called AeDES (Presidenza del Consiglio dei Ministri (2009)). Buildings subjected to earthquakes need to be classified in one of the following usability classes by AeDES:
A) the building is functional and usable;
B) the building is temporarily not usable, but it can reach the usability with small interventions;
C) the building is partially not usable);
D) the building is considered not usable, but a more in-deep examination is needed);
E) the building is not usable;
F) the building is not usable because of external risks.
The usability classes can be correlated to the limit states as follows: Usability Class "A" to LS1; Usability Class "B-C" to LS2; Usability Class "E" to LS3; "Demolition and Reconstruction" to LS4.
Libro Bianco reports the repair/reinforcement costs related to the AeDES Usability Classes and some of the building features, as structural materials, age of construction and number of floors (e.g. 269.18€/m^2 for R.C. buildings, built in 1946-1961, classified as B-C). For LS1, corresponding to usability class "A", no data from techno-economic analysis of L'Aquila earthquake are available. For this class, market information about small repair activities can be used.
The expected losses for each limit state can be estimated by using the following expression:

$$L_i = C_i \cdot (P_i - P_{(i+1)}) \qquad (14)$$

being L_i the expected earthquake economic losses related to the i-th limit state; C_i the repair/replacement costs of the considered building related to the i-th limit state; P_i and P_{i+1} the probabilities of exceeding, respectively, the i-th and the $i+1$-th limit state.
Finally, the total earthquake expected losses, related to the whole lifespan of the building, can be evaluated as the sum of the expected losses for each limit state:

$$L = \Sigma_{i=1} [C_i \cdot (P_i - P_{(i+1)})] \qquad (15)$$

3.3.4 Initial costs

The building initial costs can be evaluated by means of the market information provided by each Member State. Italian Chamber of Commerce and the Construction Contractors Associations give the price list of the construction typologies, for each building use, providing the €/m^2 value of a benchmark building. Therefore, initial costs can be evaluated as the product of €/m^2 of the building typology and the floor area of the building.

Finally, the total cost for structural performance assessment, C_{TOT} is evaluated with Equation 4.

3.4 Global assessment parameter

As for building level, the global assessment parameter, R_{SSD} can be evaluated with Equation 5.

4. CONCLUSIONS

The study herein performed moves from the sustainable structural design (SSD) methodology, an efficient and solid methodology aiming at guiding the sustainable construction sector toward a multi-performance approach, which jointly considers environmental and safety issues.
The described study demonstrates that SSD methodology is applicable at territorial level. A framework to extend SSD at national/regional/urban level has been presented by developing the four steps of the method itself. In the first step, the energy consumptions of buildings have been analyzed considering two different approaches and data sources: (i) international and European energy databases and (ii) energy performance certificates. Moreover, a study on the available usable floor area of buildings has been conducted, whereas some energy data are provided as energy consumption per square meter. In the second step, life-cycle assessment of buildings is performed by using the data provided by the first step and the percentage values provided by the research community; thus, equivalent carbon dioxide emissions of groups of buildings are evaluated. Third step aims at the evaluation of safety performance of buildings, and seismic safety is taken as an example. The economic losses, due to hazard events, and the initial costs of buildings are calculated. The Buildings data gathering and the classification are essential to perform safety assessment, in order to treat groups of building having similar characteristics as a single building. Loss assessment is then performed on the basis of the performance-based assessment methodology and using repair/replacement costs provided by existing post-earthquake costs data. The fourth and last step consists in the assembly of the results provided by previous steps, to evaluate the global assessment parameter which collects in a single economic value all the environmental and the safety issues of buildings.
SSD methodology, if applied to small and big areas, could be a solid methodology for supporting the administrations in addressing the policy projects on the territory.
Nevertheless, the study herein presented has highlighted some critical aspects related to the methodological development. Firstly, no sound data on national and regional usable floor area of buildings are available, resulting in a difficult evaluation of energy consumption. A study on prices of all the energy components should be conducted in order to provide a more complete value of energy performance parameters. Moreover, a field survey on buildings at regional/urban level is necessary in order to treat groups of buildings having similar characteristics as single building; the field survey should be finalized with the grouping of buildings having same label and according to Syner-G taxonomy. Another aspect to be considered is the necessity of collecting techno-economic studies regarding repair/replacement costs from worldwide-occurred earthquakes. Finally, a pilot study should be conducted as application of the SSD Methodology at urban, regional and national levels, in order to show the potential of the methodology.

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