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A critical discussion on the earthquake risk mitigation of urban cultural heritage assets

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ABSTRACT

This paper aims at providing a comprehensive review on disaster risk mitigation of urban cultural heritage assets located in historical centres, by providing a holistic framework on the features of such a complex system. From all the hazards and threats that can possibly harm cultural heritage assets, particular focus will be given to earthquake risk. The review of the state of science in which the earthquake risk mitigation concerns is considered fundamental to understand the current streams of thought and to identify new research gaps and opportunities to enhance the knowledge level on this particular field of research.

1. Introduction

This first section aims at highlighting some of the most relevant phenomena and external pressures affecting urban cultural heritage worldwide. In the past decades we have witnessed an increased political focus on cultural heritage, not only because of higher public interest in heritage related issues but also because cultural heritage is often seen as a means to stimulate economic activity in countries with economic downturn problems. In fact, cultural heritage is often perceived as “a powerful engine of economic development” [1], as it participates directly in the generation of economic value through, for example, tourism activities [2]. When addressing urban cultural heritage, one should adopt a holistic approach to take into account the multitude of intrinsic features of these complex systems, such as social, cultural, historic, artistic and architectural, economic, city planning and sustainable development aspects. The need for this holistic approach derives from the dynamic nature of cities, the shape of which is continually changing according to society's demands over time. Therefore, to preserve urban cultural heritage sustainably, UNESCO suggests that strategic and dynamic alliances need to be built between various actors in the urban scene, foremost between public authorities that manage the city and developers and entrepreneurs that operate in the city [3].

There are multiple causes that have been identified as responsible for transforming urban settlements and their historic areas in drivers of economic growth in many regions of the world, acquiring a new role in both cultural and social life, such as the sharp increase in the world's urban population, the scale and speed of development and the changing economy [4]. However, if this transformation and economic growth are not conducted in a controlled and sustainable manner, it may foster the development of undesirable phenomena in urban cultural heritage, such as urbanisation and globalisation, market exploitation and mass tourism, for example.

According to the United Nations [5], it is estimated that 54% of the world's population lives in urban areas in 2014. If in 1950 this percentage was estimated in 30%, by 2050 it is expected that 66% of the world's population will live in urban areas. This unprecedented and generalised urbanisation phenomenon observed in many urban areas might trigger the fragmentation and deterioration of heritage [4]. However, in many other urban areas across the globe, the opposite scenario has been observed, where several factors have been contributing to this loss of centrality and the exodus of historical centres: poor conservation state of buildings; increased air pollution rates; increased criminality and insecurity rates, and poor accessibility [6,7]. In order to aid reversing this phenomenon up to more balanced and sustainable terms, Laprise et al. [8] have developed an innovative study about regeneration strategies for disused urban areas. In the same scope, Radoslav et al. [9] have focused on the search for new revitalisation strategies of historical city centres.

Before going into further details on this subject, it is yet opportune to clarify the concept of urban cultural heritage. To understand this concept, one should recall to the classification proposed by Abbas et al. [10], in which architectonic assets are categorised based on a strictly “mechanical” criteria that foresees the identification of the most relevant macroelements in historical buildings and on the prevailing damage mechanisms which they may be subjected to. According to the same authors [10], the need for this classification arose from the

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recurrent observation of certain damage patterns in function of the assets' morphology (architectural form, proportions) and technology (type of masonry, nature of horizontal diaphragms, effectiveness of wall-to-wall and floor-to-wall connections), as these behavioural dissimilarities call for different modelling approaches and different damage variables.

In this study, attention will be given to the category of architectonic assets theoretically subjected to prevailing in-plane damage proposed by Abbas et al. [10]. Hence, the definition of urban cultural heritage assets understands not only buildings theoretically subjected to prevailing in-plane damage, but also those classified or in the process of classification, such as residential buildings, palaces and other public and service buildings with accredited cultural relevance. Moreover, this type of assets is mostly located within historical centres, as outlined in [11–13], requiring, for this reason, a distinct care, and subsequently, a different category.

From the cultural heritage viewpoint, this study aims collaterally at promoting the preservation and conservation of ancient building technologies, in order to avoid the loss of identity and the mischaracterisation of historical centres to the so-called new technologies. Moreover, in a time in which more and more economic arguments seem to dominate the decision-making process, it is indeed important to emphasise other, no less important arguments, such as the patrimonial value or the sustainability in safeguarding cultural heritage.

2. Disaster risks to urban cultural heritage assets

Over the past several years, there have been numerous large-scale disasters across the world, which have caused enormous loss of life, property and widespread damage to cultural heritage, such as the 2016 Amatrice earthquake [14] sequence or the still on-going armed conflict in Syria [15]. Given the current rate of urbanisation, and the inherent risks that are faced by densely populated urban areas, there is an increasing need for a specific approach to assess and manage the risk of cultural heritage in these areas. Moreover, a large part of this heritage, which expresses our cultural identity, is still highly vulnerable to both natural and technological hazards due to the lack of resources and planning currently made available for cultural affairs. In addition, these disasters have caused widespread damage to the cultural heritage of these cities [16].

As one might be aware of, many UNESCO world heritage properties are exposed to several hazards and threats, which may threaten their integrity and compromise the values of the Convention, and trigger irrevocable consequences to both local communities and cultural heritage assets itself, in situations where local authorities and site managers are unprepared. UNESCO [17] understands that disaster risks to cultural heritage come from both external and internal causes. While external causes are associated with the disturbance or damage to cultural heritage sites motivated by several hazards such as earthquakes, tsunamis, destructive sabotage, or military conflicts, internal causes are related to the intrinsic fragility of a determined cultural heritage asset and its sensitivity to the surrounding environment, which contributes to the asset vulnerability. Wang in [18] proposed a different assemblage for disasters with the potential to harm cultural heritage based on the predictable nature of disasters.

In this paper, however, emphasis will be given to earthquakes, as they are still one of the most destructive hazards to urban cultural heritage in Portugal [19], and in most of the Mediterranean countries [14,20–22]. Therefore, it is clear that proactive measures to reduce risks to cultural heritage from catastrophic events through adequate mitigation and preparedness should be implemented. These measures should be set together by skilled professionals, administrators and policy makers, and must respect both the principles of risk management and the historic, aesthetic and other values of cultural heritage. Bearing in mind the above, and given the lack of international guidelines concerning disaster risk mitigation and structural assessment of urban cultural heritage, the present literature review features a brief policy-driven framework covering some of the most relevant challenges and projects recently carried out on this subject.

3. Earthquake risk mitigation of urban cultural heritage assets

Earthquake risk mitigation is today placed as a top priority in the political agenda of most of Mediterranean countries' governments. Recent devastating earthquakes raised the awareness of scientists and national civil protection bodies and encouraged the development of proper risk mitigation strategies geared for earthquake risk in urban areas, which can be found for example in [16,23–29]. These strategies, recently assembled by Maio et al. [30], are typically focused on identifying the most vulnerable zones within urban areas, which are often associated to historical centres, in order to enhance both the response and recovery capacity in the event of an earthquake. Neglecting the implementation of adequate risk mitigation measures limits the response and recovery capacity after a disaster. Hence, identifying and perceiving the potential hazards affecting urban cultural heritage is imperative to guarantee effective post-event response [13].

Investing in prevention is obviously the most cost-wise strategy to mitigate earthquake risk, being, therefore, one of the reasons this literature review is essentially focused on preventive strategies to mitigate the earthquake risk and vulnerability of Urban Cultural Heritage assets.

The following measures were suggested by Maio et al. [30] for the improvement of preparedness and urban resilience of communities located in seismic-prone areas:

- Development of effective communication, warning and response systems, adequately integrated in the plans of action;
- Development of emergency, escape, rescue and rehabilitation plans, which might be rapidly activated in the event of a seismic catastrophe;
- Development and execution of awareness-raising campaigns targeted to citizens, with a strong educational component on the recommendable procedures in the event of an earthquake and the basic information concerning earthquake risk;
- Development and following up of prevention and earthquake risk mitigation plans by governmental authorities and civil protection bodies;
- Setting up of life and damage insurance special schemes for earthquakes, in order to enhance the recovering capacity of the affected victims and to enable international funding to reach more victims;
- Early establishment of search and rescue teams, as well as of volunteering groups;
- Preparation of financing mechanisms for rehabilitation and reconstruction programmes, ready to be activated at any time;
- Implementation of training programmes and emergency drills to identify and correct eventual flaws in the action plans.

Earthquake risk mitigation of Urban Cultural Heritage assets should involve at least three fundamental elements highlighted in the diagram of the following Fig. 1, hazard, vulnerability and exposure, and can be approached at three main different phases of a disaster, as it will be further detailed below: pre-event, emergency and response, and post-event. The seismic vulnerability can be understood as the intrinsic predisposition of an element to suffer damage from a seismic event of a given intensity, and is considered by many authors, as for instance Caicedo et al. [31], as the most eager element to be mitigated, which by means of adequate strengthening and retrofitting measures is able to contribute more efficiently to the mitigation of earthquake risk of cultural assets. For this reason, the next section will be exclusively dedicated to the literature review of seismic vulnerability assessment methodologies suitable to Urban Cultural Heritage assets.

Thus, the preservation of cultural heritage assets must guarantee not only their capacity of lasting over time against natural decay without

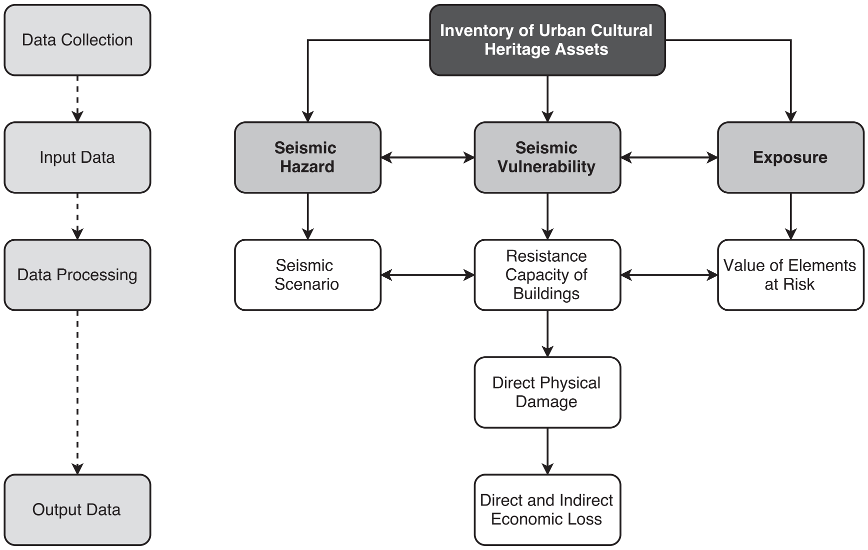

Fig. 1. Flow diagram with the fundamental elements and steps for the assessment of earthquake risk in Urban Cultural Heritage assets.

losing their authenticity and usability but also their capacity to withstand natural hazards and extreme events with limited and expected structural performance. This means that the need of guaranteeing an "acceptable level" of structural safety for building's occupants should be always related to the principle of "minimum intervention" on the building itself. However, the definition of "acceptable" safety levels, as well as the concept of "safety", still represents an open issue in which concerns monumental buildings [32]. Thus, their risk assessment is a challenge regarding not only structural and architectural components but also both movable and unmovable artistic assets contained in them.

The causes and consequences associated with earthquake risk mitigation of existing structures have been acknowledged by the European Union, which has expressed great concern about this issue, either by supporting the development and implementation of Eurocodes, supplementary coordination of Civil Protection bodies or even funding numerous research programmes in this particular field, as the EU-CHIC [33], ONSITEFORMASONRY [34], PROHITECH [35], NIKER [36], or the PERPETUATE [37,38] research project. The later was recently funded by the European Community's Seventh Framework Programme, and aimed at developing a methodology for the assessment of seismic risk of cultural heritage assets and framework for the design of interventions. The main goal consisted in developing European Guidelines for the evaluation and mitigation of seismic risk to cultural heritage assets, applicable in the European and Mediterranean North African countries. The strategy adopted in this project to address this very important but complex issue is presented in Fig. 2.

However, there is still much to be done in this regard, particularly in

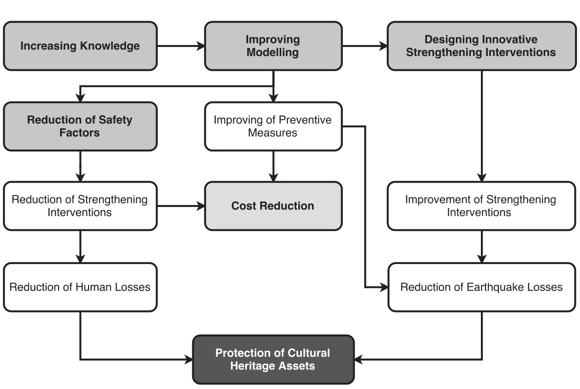

Fig. 2. Flow diagram of the strategy proposed in the PERPETUATE project to Cultural Heritage assets.

which concerns the oldest and most vulnerable building stock constructed without anti-seismic provisions, often referred to as non-engineered buildings. Furthermore, these cultural heritage assets were not based on an engineered design, underwent many transformations over centuries and often reveal a lack of efficient connections among structural elements, being therefore considered highly vulnerable to earthquakes.

Within the broad range of typological classes and building materials that might be included in the definition of Urban Cultural Heritage assets, masonry structures are one of the most common not only in Europe, but worldwide. Hence, in order to mitigate the earthquake risk of such structures, it is necessary not only to develop reliable models, able to simulate their earthquake response, and adequate performance-based assessment procedures, aiming to guarantee the acceptable level of risk for the occupants and for the conservation of the asset itself, but also to account for uncertainties that should be interpreted and differentiated with regard to their type and source.

3.1. Pre-event phase

The idea of "preventive conservation" is now the primary focus of cultural preservation worldwide [18]. The use of friendly-user multi-risk assessment tools, connected to relational databases within GIS (Geographical Information System) environments, through which it is possible to manage data regarding the construction characteristics, the conservation state or the seismic vulnerability of historical building stocks, as well as to perform integrated risk assessment analysis, loss scenario, and cost-benefit analysis, has become essential to predict cultural heritage vulnerability and fragilities, proving a global and spatial view of the area under study by both professionals and decision-makers. In this sense, on the one hand, owing both the general poor conservation state and the high vulnerability, normally associated with urban cultural heritage assets, it is crucial the implementation of adequate structural strengthening measures for mitigating this vulnerability and therefore, the associated risk.

On the other hand, forces should be also concentrated on raising communities' preparedness, awareness, and perception concerning earthquakes and the value of cultural heritage. This is only possible through the implementation of proper education and communication strategies. The factors that affect how risks are perceived determine a person's emotional response to risk information [39]. Levels of fear, worry, anxiety, anger, and outrage tend to be lowest when a risk is perceived to be well understood, relatively well known to science, that produce "statistical victims" and are caused by nature or "Act of God"

[40]. One of the most common ways to increase risk awareness and assess the risk perception of communities is the creation and dissemination of both information and communication tools, as well as the organisation of risk awareness campaigns. Finally, volunteering and aiding mechanisms should be established in order to build capacity for the emergency and response phase.

3.2. Emergency and Response Phase

In this phase, the key priority is the safeguarding of human life by implementing rescue action plans. Thus, the promptness of volunteers, Non-Governmental Organisations (NGOs), neighbouring countries and external partners on supporting this response actions will define the preparedness level of a determined urban cultural heritage asset. These actors are particularly important in terms of social support activities The second priority usually concerns the endowing of temporary settlement camps and infrastructures to receive homeless and injured people. In addition, medical aid and psychological support should be also rapidly made available. Moreover, it is in the emergency and response phase that the first in-field technical surveys are carried out to assess the level of damage inflicted on infrastructures. These surveying activities are usually conducted on the basis of a strong cooperation between the scientific community and the civil protection bodies. Some insightful considerations concerning the main framework of the emergency plans for Portugal and worldwide can be consulted in [30].

3.3. Pos-event phase

Even though the damage assessment of infrastructures is initiated quite soon in the emergency and response phase, these activities are very likely to continue several months following the event, being, therefore, a very demanding and complex task since it involves in-field cooperation of different players. Given their particular structural complexity or economic value, cultural heritage assets require very detailed surveying and the judgement of top-level expertise. The following priority measures are usually taken into consideration in the post-event phase: temporary sheltering; recovery of local public system as a whole; revitalise local economy and transport networks; structural retrofitting or strengthening interventions of industrial infrastructures and in urban cultural heritage. In addition, containment works should be promptly carried out in order to avoid further degradation and the extent of the damage in Cultural Heritage assets. Usually, these containment works are implemented by means of provisional tie-rods, steel strapping or wooden containment structures, as outlines for example in [41,42].

4. The context of earthquake risk in Portugal

The last decade has been marked by an unceasing dialogue between, the Portuguese scientific community and the Portuguese Society for Seismic Engineering (SPES), and the public authorities and governments' leaders, regarding the urgent need to promote active actions to mitigate the earthquake risk in Portugal. The actual government aimed at promoting actions to catalyse and renew the Construction Sector, which has been largely debilitated by the economic crisis that Portugal has faced until just recently. Regulated by the Ministry of Environment, Territorial Planning, and Energy, the strategic instrument that was chosen to pursue such goal was "building rehabilitation" [43]. In which concerns Seismic Safety, this instrument states that the non-aggravation of buildings' actual vulnerability to earthquakes is the only requisite that builders and engineers have to comply in order to get their respective use license [44]. According to CENSUS 2011 [45], pre- and moderate-code buildings (buildings designed and constructed before 1990 [46]) represent about 62% of the total building stock in Portugal, meaning that the renewed and promoted real estate market might soon be restocked with buildings that are far from being conveniently seismic-designed, compromising, therefore, the safety of citizens and the wealth of real estate owners at stake [43]. Merging the chronological evolution of earthquake risk research with some of the most important milestones and facts that have been influencing the level of preparedness and perception regarding earthquake risk in Portugal ever since the great Lisbon earthquake in 1755, is fundamental to better understand the context of earthquake risk mitigation in Portugal. This exercise was recently carried out by Mota de Sá in [43]. Additionally, it is worth referring the work developed in Maio et al. [30], which provides an insightful overview of some of the existing strategies for the earthquake risk mitigation at the national scale, by focusing on the review of some of the most widely used methodologies for earthquake risk assessment, risk mapping, public information mechanisms, early-warning systems and emergency planning.

5. Seismic vulnerability and risk assessment

Risk analysis encompasses a broad set of necessary instruments, such as multi-criteria decision analysis, probability analysis, Bayesian networks, event trees, fault trees, Monte Carlo simulation, which are far from being accessible by non-academic audiences. If not carefully used, they may lead to erroneous conclusions and decisions supported by "recognised scientific knowledge", with undesirable and serious impacts and consequences in several domains [43]. Even if an adequate method for measuring the impact of earthquakes on multiple criteria was developed, aggregating the results at a convenient scale remains a challenge [43]. The process of ranking solutions with respect to risk, a common goal of complex approaches, is usually hindered by a broad degree of inconsistency [47] and the aggregation of multiple criteria in a unique final number to classify risks can result in an aleatory combination of contents [48]. According to Mota de Sá [43], despite the merit and contributions of these approaches as a result of their complexity, the number of variables involved, their degrees of uncertainty, and the ways in which they are combined, render these models too hard to understand by non-academic audiences and so mostly useless to citizens and stakeholders. Furthermore, given conflicting interests, and lack of understanding of scientific findings and reasons, final decisions are often based on political and economical reasons rather than technical issues, as mentioned by Hunter and Fewtrell [49].

As already referred, seismic vulnerability is an inherent property of buildings that reflects their predisposition to suffer damages due to ground motions, which is associated to their physical and structural capacity. This field of research has been developed according to different streams of thought over the years, hindering the possibility of achieving a unique and consensual classification categorisation of all the existing methodologies. One of the first proposals for such a classification was given by Corsanego and Petrini [50], in which seismic vulnerability assessment methodologies were categorised in four main groups, as a function of the potential of their output: direct; indirect; conventional, and hybrid methodologies.

Calvi et al. [51] instead, has classified these methodologies in the following categories: empirical; analytical, and hybrid. The stream of thought implicit in empirical methods usually fall upon damage probability matrices, first proposed by Whitman et al. [52], vulnerability index methods, first developed by Benedetti and Petrini [53] and further adapted to the Portuguese building stock by Vicente et al. [54], continuous vulnerability curves, or screening methods, for example. Analytical (or mechanical) methods instead, tend to feature slightly more detailed and transparent vulnerability assessment algorithms with direct physical meaning, that not only allow detailed sensitivity studies to be undertaken, but also the straightforward calibration to various characteristics of building stock and hazard sources [51]. Finally, hybrid methods have demonstrated their usefulness in particular when there is a lack of damage data at certain intensity levels for the geographical area under consideration. Additionally, hybrid methods can also be used to calibrate analytical models [51]. These methods combine post-earthquake damage statistics with simulated, analytical damage statistics from a mathematical model of the building typology under consideration, as demonstrated in research developed by Giovinazzi [55], for example.

Chever in 2012 [56] has proposed a classification defined in function of the scale and the purpose of each methodology, which is indirectly associated with the resources and time available for carrying out the required assessment. This will in turn dictate the type of approach or methodology to be used, and thus, the level of accuracy and type of output. In Chever's proposal, these methodologies can essentially operate at the following assessment scales: that of thousands of buildings, as for example in Silva et al. [57]; few hundreds to few dozens as in Vicente et al. [54] or D'Ayala and Speranza [58], and of individual buildings, as for example in Marques and Lourenço [59], or in Maio et al. [60]. Moreover, according to Chever [56], the assessment scale is associated with the objective of the methodology, which varies from large-scale vulnerability and earthquake scenario, screening and prioritising into a building stock, and an initial estimation of individual vulnerability, respectively.

5.1. Criteria for the classification of methodologies

Even though there are several other proposals for the classification of seismic vulnerability and risk assessment methodologies for masonry buildings in the current literature [55,61–65], there is still a clear lack of consistency in the terminology used in these studies. For the sake of simplicity, and given the vast number of reviews focusing on the discussion of some the most widely used methodologies, the authors aimed in this section at providing a consistent and consensual criteria for the classification of such methodologies, that directly or indirectly understand the most distinct aspects underscored by the above-mentioned authors. Thus, instead of developing a new criteria with an entirely new technical terminology, the authors aimed at promoting a shared understanding among the global scientific community, concerning the taxonomy used for classifying seismic vulnerability and risk assessment methodologies. The criteria given in the following Fig. 3 was adopted from Boschi [65], for being, to the authors' understanding, a very complete and comprehensive classification proposal, which consists of the categorisation of three fundamental aspects: the detail level, type of output, and data and assessment tools' quality. Each one of these aspects is going to be addressed in the following sub-subsections.

5.1.1. Detail level

This first aspect concerns to the "level of detail" of the elements under study and it is highly reliant on the detail of the input data available and on the purpose of the assessment. This aspect is addressed in [56,65], however by means of a different terminology. As shown in the flow diagram of Fig. 4, there are three different approaches to assess seismic vulnerability of increasing level of detail, so called: first; second, and third level approaches.

First level approaches are suitable to large-scale assessments (e.g. urban areas) and include methodologies that resort to large amount of simple and mainly qualitative data. According to Boschi [65], the level of detail of the input data is not sophisticated, and it is usually provided either by census data, municipalities' archives, or through "in situ" survey and inspections. Examples of this type of approach can be found

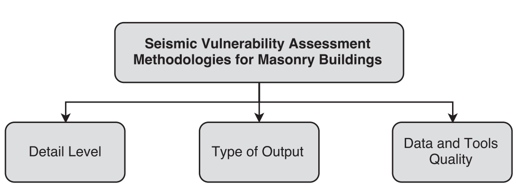

Fig. 3. Criteria for the classification of existing methodologies for the seismic vulnerability and risk assessment of masonry buildings.

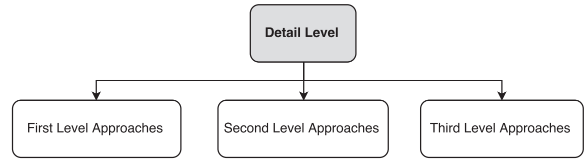

Fig. 4. Detail level of existing methodologies for the seismic vulnerability and risk assessment of existing buildings.

in [54,57].

Second level approaches are based on mechanical models that rely on a higher quality of information (geometrical and structural) of the building stock, as the case of the studies carried out by D'Ayala and Speranza [58] or by Restrepo-Vélez and Magenes [66], for example.

Finally, third level approaches involve the use of numerical models that require a complete and rigorous survey of individual buildings and a throughout knowledge of geometry and materials' properties of the all the structural elements, as the case of the 3Muri® FME program [67] or the DIANA® FEA [68] software. When moving from first to third level approaches one should be aware of the following consequences:

- Increased computational effort resulting from shifting from rapid or simplified to detailed structural analyses;
- The need of more specialised and skilled workforce;
- Shifting from large-scale (building stock) to individual buildings assessment.

5.1.2. Type of output

The second criterion refers to the type of output or "intended results" of these methodologies (in Fig. 5), an aspect that was first addressed in Corsanego and Petrini [50] and that has been adopted by many scientists ever since, as Calvi et al. [51] or Vicente et al. [54]. In 2016, Boschi [65] adapted this criterion that distinguishes the existing methodologies in three main groups: direct; indirect, and hybrid techniques. These techniques differ on the number of steps involved in the definition of the risk evaluation.

Direct techniques use only a one-step process to estimate the damage caused to a structure by an earthquake, and usually employ two different types of methodologies: typological and mechanical. Typological methodologies assign typological classes to each structure located within the building stock, accounting for different aspects that influence the seismic response of each class, as in the case of Damage Probability Matrixes methodologies [69,70]. The damage probability of a determined building class is then determined through post-event damage observation data. On the other hand, mechanical methodologies represent structures either through simplified [58,71] or more detailed models [67,68].

Indirect techniques, instead, require a two-step process to estimate damage. Vulnerability index-based methodologies (also known as "scoring methods") are one the best examples of indirect techniques, and can be found in [13,53,72]. In this type of methodologies, seismic vulnerability in the form of an index is estimated in a first phase either through available information (census data or municipalities' archives, for example) or "in-situ" survey and inspection campaigns. In a second phase, the damage associated with each structure is estimated by using existing statistically-based correlations derived from post-event damage

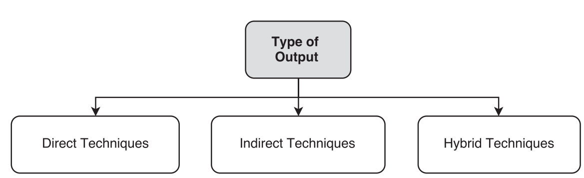

Fig. 5. Type of output of existing methodologies for the seismic vulnerability and risk assessment of masonry buildings.

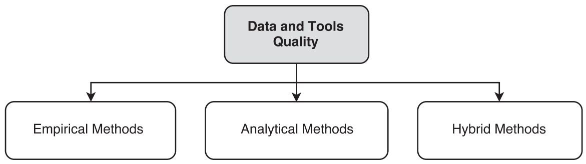

Fig. 6. Data and tools quality of existing methodologies for the seismic vulnerability and risk assessment of masonry buildings.

observation data.

Finally, hybrid techniques combine both direct and indirect techniques' features. An example of such technique is the macrosseismic method developed by Lagomarsino and Giovinazzi [73], as it combines the characteristics of typological methodologies (direct) and indirect techniques, by using vulnerability classes defined in the EMS-98 scale [74] and a vulnerability index, respectively.

5.1.3. Data and tools quality

The third and final criterion, shown in the following Fig. 6, concerns to the quality of the input data and the tools (or methods) intended to be used in the assessment, and covers the same three categories as in the classification proposed by Calvi et al. [51], which was introduced above: empirical; analytical, and hybrid methodologies. In the following paragraph, each category will be explained in detail, according to the former classification.

Empirical methods are either based on expert's judgement opinions or on post-event damage observation data. The results of empirical methodologies are usually given in two different types: damage-motion relationships such as damage probability matrices (DPM), as in [69,70], and fragility curves, as in Jaiswal et al. [75], for example. As these methodologies are used for large-scale assessments (first level approach) they usually require the qualitative evaluation of few parameters, which is often carried out through "in situ" inspections. The outputs of empirical methodologies are usually qualitative and representative of a building class or typology with common structural characteristics.

Analytical methods use mechanical or numerical procedures to evaluate the seismic vulnerability of structures, and can be distinguished between methods that use simplified approaches, to which a low computational effort is associated, and more complex methods that resort to modern and refined analyses, being therefore, more demanding in terms of computational effort. These methodologies require a large amount of information and a throughout knowledge of all structural components under study. For this reason, the adoption of analytical methods is naturally associated with small samples of buildings [65].

Finally, hybrid methods combine the two above-mentioned categories and are generally used at the urban scale, as in [76–78].

6. Intervening in urban cultural heritage assets

As it is recognised, urban cultural heritage raises significant challenges either in diagnosis, monitoring, conservation, maintenance, strengthening or retrofitting actions. This inherent complexity naturally limits the application of modern legal codes and building standards. Therefore, specific recommendations are desirable and necessary to both ensure rational methods of analysis and repair methods appropriate to the cultural context. The following paragraphs cover some of these challenges and present a strategy recently proposed for the structural assessment of Urban Cultural Heritage assets.

Seismic strengthening and retrofitting assessment of structures are often based on the verification of a target building performance level for an associated earthquake hazard level. Fig. 7 presents a flow diagram of a methodology proposed by Asteris and Giannopoulos [79] for the structural assessment of Urban Cultural Heritage assets. According to Spyrakos [80], by considering the seismic response of both structural and non-structural elements and artistic assets, performance levels may be defined in relation to different performance targets, associated with the functionality and the cultural properties of buildings. Modern seismic design codes, applicable both for the design of new buildings and for the evaluation and rehabilitation of existing ones, are based on these performance-based assessment approaches. The EC8-3 [81] specifies as $TL=50$ years the duration of "nominal life" of a structure and defines three building performance levels (limit states) considered as appropriate for the seismic protection of ordinary new buildings: near collapse; significant damage, and damage limitation. The methodology proposed by Spyrakos [80] introduced the term "nominal life of an intervention", which is defined as the time for which the intervention ensures a defined performance level. Furthermore, as historical buildings may be considered to belong to importance class III or IV, leading to large seismic requirements and actions characterised by a high return period, their preservation could most likely require invasive interventions in order to meet the safety standards for new construction [80]. However, according to the principles of interventions on historical buildings and monuments, less intrusive interventions are imposed. In general, interventions on Urban Cultural Heritage assets should satisfy the following three principles: reversibility, durability in time, and feasibility of the proposed solution.

The principles for the selection of a determined seismic vulnerability methodology should be based on the above-mentioned criteria that cover the classification of such methodologies: the "scale" of the assessment (or detail level), the type of output, and the type of data and tools used. The insightful discussions about the advantages and drawbacks of each methodology discussed in [43,51,65], for example, allows one to better understand the most significant differences between some of the most widely used methodologies, and therefore to make a more sustained decision. Naturally that the likelihood of deciding for third level approaches increases when the level of detail concerning the geometrical and structural properties of our sample of buildings is high. Ideally, and according to Calvi et al. [51], an optimal methodology should: incorporate the most recent developments in the field of seismic hazard; explicitly account for all sources of uncertainty; be transversal to different construction practices and building typologies; allow for the inclusion of retrofitting measures, and find a balance between the computational effort and the amount of detailed input data that is required and the consequent degree of confidence in the results. However, it is very unlikely that a single methodology can eventually fulfil all of these requirements simultaneously. Thus, it appears that the ideal approach needs to incorporate the positive aspects of different vulnerability assessment methodologies, the so-called hybrid approaches. Independently from the nature of the approach, it is important that the outputs resulting from such methodologies are clearly oriented to end-users, meaning that they should be user-friendly and have an easily understandable language, so that they might be properly interpreted by civil protection bodies and decision-makers in general.

7. Conclusions

The present paper aimed at addressing the most important aspects concerning the earthquake risk mitigation of Urban Cultural Heritage assets. Due to the acknowledged relevance of seismic vulnerability in this system, particular attention was given to existing vulnerability methodologies for the assessment of old buildings located in historical centres, and to their respective conceptual differences. In this regard, a criteria for the classification of such methodologies, which included the most important aspects frequently covered in the literature, was presented and discussed. Finally, the major challenges regarding the protection of Urban Cultural Heritage assets were discussed.

From a policy-driven and decision-making viewpoint, the protection of Urban Cultural Heritage assets should be based on a comprehensive knowledge of the earthquake risk in order to define more proficient

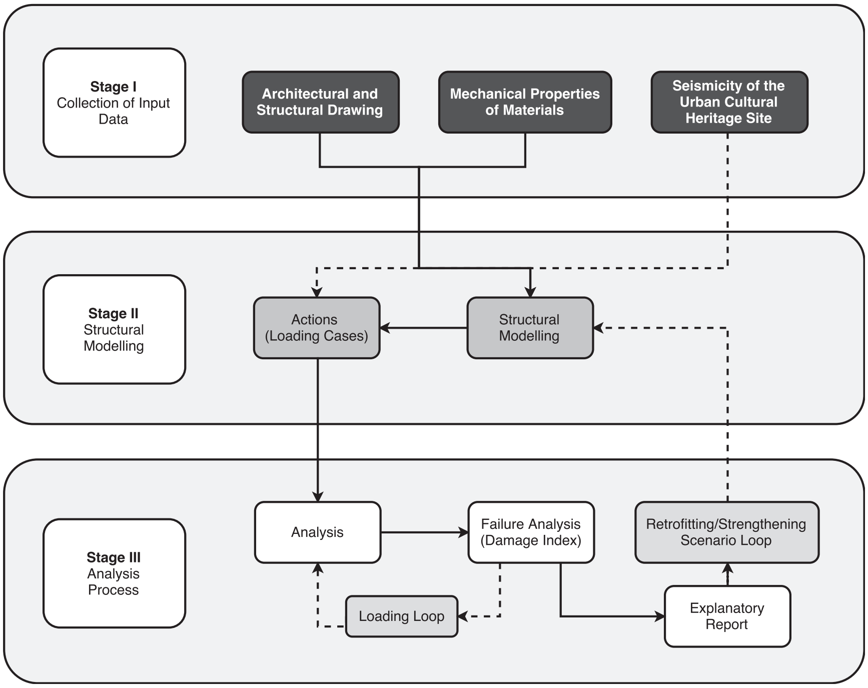

Fig. 7. Flow diagram with the methodology proposed in [79] for the structural assessment of Urban Cultural Heritage assets.

mitigation strategies and to outline strengthening interventions that can contribute to the reduction of their specific vulnerability and, consequently, for the increase of the overall resilience of the historical centres. Moreover, the need for a common approach and adequate coherent recommendations for the structural assessment of Urban Cultural Heritage assets should be further considered a must-need priority. From the risk modelling and analysis viewpoint, if on the one hand it is fundamental to properly address uncertainties and inconsistencies often concealed in estimations, avoiding this way disseminating erroneous conclusions and biased results, on the other hand, however, it is not less important that risk intensity measures or indicators can be easily understood and interpreted by citizens, governmental and civil protection authorities, and other stakeholders.

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