A multi-hazard risk ~~prioritization~~ prioritisation framework for cultural heritage assets

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Abstract. Multi-hazard risk assessment of building portfolios is of primary importance in natural-hazard-prone ~~areas~~regions, particularly for the ~~prioritization~~ prioritisation of disaster risk reduction and resilience-enhancing strategies. In this context, cultural heritage assets require special consideration because of their high vulnerability to natural hazards - due to ageing and the type of constructions - and their strong links with communities from both an economic and a historical/sociocultural perspective. ~~As part of the *Cultural Heritage Resilience & Sustainability to multiple Hazards* (CHeRiSH) project, funded by the UK Newton Fund, this~~This paper introduces a multi-hazard risk prioritisation framework specifically developed for cultural heritage assets. The proposed framework relies on a multi-level rapid-visual-survey (RVS) form for the multi-hazard exposure-data collection and risk ~~prioritization~~ prioritisation of case-study assets. Because of the multi-level architecture of the proposed RVS form, based on three levels of refinement/information, an increasing degree of accuracy can be achieved in the estimation of structural vulnerability and, ultimately structural risk of the considered assets. At the lowest level of refinement, the collected data ~~are~~ is used for the computation of seismic and wind risk ~~prioritization~~ prioritisation indices, specifically calibrated in this study for cultural heritage assets with various structural/non-structural features. The resulting indices are then combined into a unique multi-hazard risk prioritisation ~~prioritization~~ index in which the intangible value of cultural heritage assets is also considered. This is achieved by defining a score expressing the cultural significance of the asset. The analytic hierarchy process is extensively used throughout the study to reduce the subjectivity involved in the framework, thus obtaining a simplified, yet robust~~,~~ approach which can be adapted to different building typologies. The proposed framework is applied to 25 heritage buildings in Iloilo City, Philippines, for which innovative, non-invasive techniques and tools for improved surveying have also been tested. Thermal and omnidirectional cameras have helped in the collection of structural data, together with drones for the inspection of roofs. Results of the study are presented and critically discussed, highlighting advantages and drawbacks of the use of new technologies in this field.

1 Introduction and motivations

Probabilistic risk assessment of building portfolios in natural hazard-prone ~~areas~~ regions is of paramount importance to define prioritisation ~~prioritization~~ schemes for the design, ~~/~~implementation, and ~~/optimization~~ optimisation of disaster-risk-reduction (DRR) and resilience-enhancing strategies. This is even more important in developing countries, where most of the existing building stock has been designed and ~~/~~built according to obsolete codes (if any) and limited financial resources/coping capacities are available.

In this context, cultural heritage (CH) assets require special consideration because of their physical vulnerability, which has been highlighted during recent catastrophic events (e.g., Fiorentino et al., 2018; World Bank Group, 2017), and their sociocultural value (e.g., European Commission, 2018). In fact, the lack of any hazard-resistant design (in most of the cases) and the presence of material degradation due to aging, together with the possible presence of structural modifications/local repair and/or partial/total reconstructions over time, result in high levels of vulnerability characteri~~z~~sing those assets (e.g., Despotaki et al., 2018; D'Ayala, 2014). In addition, assessing ~~the~~ expected losses for a given set of hazard scenarios is a complex task because of the tangible and intangible values of CH assets (e.g., European Commission, 2018). The tangible value is mainly related to structural/architectural characteristics (direct losses), often hardly quantifiable due to the uniqueness of a given asset, and to the link with the economy of a region through cultural tourism (indirect losses). Moreover, CH has a symbolic value for a given community. The ~~citizens'~~ feeling of place and belonging by citizens and the sense of collective purpose are strongly linked to CH assets: their damage and partial/total collapse can have a huge impact on social cohesion, sustainable development and psychological wellbeing. These aspects provide CH assets with an intangible value, which must be somehow considered in the risk assessment both at portfolio and building-specific level. All these issues together make the quantification of CH-asset exposure (i.e., the value at risk) a challenging task (e.g., European Commission, 2018).

An urgent need for integrating the specific features of CH assets into DRR plans has been recently highlighted by various national and international authorities across the world. One of the first published documents in this context is the report prepared by the World Heritage Committee (UNESCO, 2008), which stated that *'most world heritage properties, particularly in developing areas of the world, do not have established policies, plans and processes for managing risk associated with potential disasters'*. In 2015 the UN General Assembly endorsed the *Sendai Framework for Disaster Risk Reduction 2015-2030* (UNISDR, 2015) which, for the first time, explicitly included CH in the overall agenda of DRR. The framework clearly ~~recognizes~~ recognises culture as a key dimension of DRR, with CH specifically referred to under two priorities: (1) understanding disaster risk; and (3) investing in DRR for resilience. However, the sector could also contribute significantly to priorities such as (4) enhancing disaster preparedness for effective response. These directions were transposed at European level through the publication of the *Action Plan on the Sendai Framework for Disaster Risk Reduction 2015-2030* (SWD, 2016), which promoted the collaboration between the public (e.g., governments) and the private sector (e.g., engineering consultancies, (re)insurance companies) for the implementation of resilience-enhancing strategies for CH assets. Following this idea, for the first time, in 2018, an insurance company ~~has been~~was instructed by the Episcopal Conference in Italy (CEI) to provide a (re)insurance policy for religious buildings from natural catastrophe risks in all 25,796 parishes of the 225 Italian dioceses, thus boosting the interest of (re)insurance companies and risk modellers in the CH-asset market (Sheehan, 2018).

Any DRR strategy, designed by governmental agencies or other stakeholders, should be based on a rational understanding of natural-hazard risks of large building stocks. However, performing detailed structural analyses for a large number of structures is cost-ineffective because it would require high-performance computing and specific technical resources. Therefore, simplified methods for multi-hazard risk prioritisation ~~prioritization~~/assessment of building portfolios (e.g., FEMA P-154, 2015), framed in multi-level frameworks (e.g., Moratti et al., 2019), represent essential tools to ~~prioritize~~ prioritise further detailed analyses and any DRR and/or resilience-enhancing intervention. Such simplified methods should allow an analyst to also account for the intangible value of CH assets and to consider their specific construction features by just using a small amount of information - to be typically collected in highly-complex urban settings, such as in developing countries.

This paper addresses the above-mentioned issues by proposing a multi-level, multi-hazard risk assessment framework for CH assets, with a special focus on reinforced concrete (RC) frames and unreinforced masonry (URM) buildings. The proposed framework relies on an ad-hoc rapid-visual-survey (RVS) form which can be used to gather information for different levels of analysis varying in refinement. At the lowest refinement level, the focus of this paper, it allows ~~calculating~~ an analyst to compute risk prioritisation ~~prioritization~~ indices against various natural hazards. Specifically, seismic and wind risk prioritisation~~prioritization~~ indices for CH assets are proposed. They represent an extension of those developed within the *Indonesia School Programme to Increase Resilience* (INSPIRE; Gentile et al., 2019) and the *Safer Communities through Safer Schools* (SCOSSO; D'Ayala et al., 2020~~Nassirpour et al., 2018~~) projects respectively. In particular, the INSPIRE seismic risk prioritisation~~prioritization~~ index is extended to the case of ~~unreinforced masonry (~~URM~~)~~ buildings by providing specific performance modifiers (*Section 3.2*) and calibrating their relative weights. In a similar way, the SCOSSO wind risk prioritisation~~prioritization~~ index is adapted for the specific characteristics of CH-asset roofs (*Section 3.3*). A simplified approach for the combination of the two indices, and which allows for an explicit consideration of the intangible value of CH assets (reflecting the CH~~-~~ asset significance; Kerr, 2013), is also proposed (*Sections 3.4* and *3.5*). Weights and scores used in this study are calibrated through the analytical hierarchy process (AHP; Saaty, 1980) in order to reduce the subjectivity involved in the framework.

The effectiveness of the proposed framework has been demonstrated during a field survey of 25 CH assets in Iloilo City, Philippines. With a population of 447,992 inhabitants and a 1.02% population annual growth rate, Iloilo City is one of the most highly-~~urbanized~~ urbanised cities of the south-eastern tip of Panay island in the Philippines (Philippine Statistics Authority, 2016). It is also the capital city of the province of Iloilo and an important heritage hub for tourism in the Philippines. The historic street Calle Real, located in the old downtown district of Iloilo City, is home to several fine examples of historic ~~luxury~~ buildings constructed in the first half of the 20th century during the American ~~colonization~~ colonisation (ICCHCC, 2010). Most of them have been surveyed during the fieldwork. Being located in a cyclonic region with the West Panay fault (the nearest one) just 15 km away (Yu and Oreta 2014), Iloilo City represents a perfect case study to test the proposed multi-hazard risk and resilience assessment framework.

The overall framework has been developed within the *<u>C</u>ultural <u>He</u>ritage <u>R</u>es<u>i</u>lience & <u>S</u>ustainability to multiple <u>H</u>azards* (CHeRiSH) project, funded by the UK Newton Fund, which aims to define a multi-level risk and resilience assessment framework for CH assets in the Philippines exposed to multiple natural hazards. It also investigates innovative, non-invasive techniques and tools for CH assets survey/diagnostic as well as different retrofitting approaches for Filipino CH assets, which meet conservation and adaptive reuse criteria.

2 Review of risk prioritisation~~prioritization~~ schemes for CH assets

~~A number of~~Several methodologies for the vulnerability/risk prioritisation~~prioritization~~ of buildings are available in the scientific literature and in international guidelines. These approaches often rely on the definition of pre-determined structural types (or building classes; ~~(~~e.g., Lagomarsino and Giovinazzi, 2006) and corresponding fragility/vulnerability relationships for each class; alternatively, RVS forms and empirically calibrated vulnerability/risk indices based on the RVS results (e.g., Uva et al., 2016) are used. Although a comprehensive review of the current state-of-the-art in the field is outside the scope of this paper, a brief overview of relevant risk prioritisation~~prioritization~~ procedures defined for CH assets is presented in this section.

Even though the procedure introduced by the Federal Emergency Management Agency (FEMA P-154; FEMA, 2015) is not specifically tailored for CH assets, it represents an important reference for every risk prioritisation~~prioritization~~ framework based on RVS form, like the one proposed in this study. Starting from a sidewalk screening of the surveyed building, the procedure described in the FEMA P-154 document consists of 1) definition of the ~~building~~ structural type ~~(or class)~~ by identifying the primary gravity load-carrying material of construction and the primary seismic force-resisting system; and 2) identification of building attributes modifying~~—~~ the expected seismic performance with respect to an 'average' archetype building representative of the given building class. Scores can be associated to the above features, thus determining a seismic vulnerability index without performing any structural ~~analyses~~analysis. The scoring framework is directly linked to the probability of collapse of archetype buildings (FEMA P-155; FEMA, 2015) through the Hazard United States (HAZUS) model (Kircher et al., 2006).

Lagomarsino (2006) proposed one of the first multi-level frameworks for the seismic prioritisation~~prioritization~~ of CH assets based on the estimation of the structural vulnerability. At the lowest refinement level, the approach allows ~~for the computation~~one to compute ~~of~~ a vulnerability prioritisation~~prioritization~~ index based on a macro-seismic model (i.e., which makes use of vulnerability curves obtained through post-earthquake damage ~~assessment~~ data collected ~~after earthquakes of~~ for different seismic intensities) to be used with macro-seismic intensity hazard maps. The computation of the index requires various (expert) ~~opinions~~ judgments on geometrical and structural features of the surveyed building, which are then used to determine an average vulnerability index and vulnerability modifiers. At the highest refinement level, a structural model (e.g., equivalent-frame model) is used to calculate numerical fragility curves for selected damage states ~~. Finally, these results are~~

~~used to determine (probabilistic) distributions of damage states~~ (Lagomarsino and Giovinazzi, 2006). ~~to assess the structural vulnerability, thus increasing the accuracy of the result.~~ In this procedure the CH-asset value is not directly considered.

D´Ayala et al. (2006) proposed a conceptual approach for the multi-hazard vulnerability assessment of historic buildings. The methodology is based on three steps: 1) hazard screening for the identification of the relative damageability of a given historic building; 2) selection of those hazards that can lead to damage scenarios and estimation of the expected losses through a process of building disassembly; 3) structural analyses of important building components in order to achieve a higher level of accuracy. For each hazard, the prioritisation~~prioritization~~ index is defined as a holistic score obtained by using a weighted summation of scores related to the building features (e.g., structural materials, preservation condition, geometry). Besides being one of the first multi-hazard vulnerability prioritisation~~prioritization~~ schemes, the study presented a comprehensive approach for assessing the tangible and intangible value of CH assets. In particular, significance and restorability of CH assets are used as reference criteria. The significance is defined essentially as a function of the authenticity and originality of the CH asset, i.e. of its historic and aesthetic character. Its evaluation is based on a wide range of criteria including social, cultural and economic attributes. Whereas, the evaluation of the restorability requires a decision making relative to possible interventions and successful outcomes. In addition to cultural and architectural criteria (e.g., acceptability of restoration), the restorability of a damaged building depends on objective factors, such as availability of original building materials, information on the original structural features and substantial financial support. Finally, indices related to different hazards are combined by using ~~normalized~~ normalised losses of common building typologies in the region with reference to a particular peril as weights.

Yu and Oreta (2015) presented a multi-hazard risk prioritisation~~prioritization~~ scheme for CH buildings which explicitly considered the asset value. The risk prioritisation~~prioritization~~ index is defined as the weighted summation of mitigation and vulnerability factors, whose relative importance is considered through the use of the AHP for the calculation of the weights. The authors proposed an innovative procedure for the quantification of the tangible and intangible value of CH assets based on both objective and subjective criteria. The asset value is determined by "Cultural Heritage" factors, such as architectural and historical values, and "Economic/Tourism" factors, such as commercial use, tourism importance and adaptive reuse adaptability. The total asset value is given by the weighted summations of all these characteristics, where the weights are calibrated through the AHP and based on expert judgments. The scores related to each characteristic are derived through a "focus group discussion" consisting of different stakeholders, such as technicians, historians and inhabitants.

D'Ayala et al. (2016) proposed a procedure for the multi-hazard vulnerability prioritisation~~prioritization~~ and assessment of CH assets based on structural models and synthetic scores related to information gathered ~~in~~ through a specifically-defined RVS form. In particular, the Failure Mechanisms Identification and Vulnerability Evaluation (FaMIVE) method (~~D'ayala~~D'Ayala, 2005; D'Ayala, 2013) is used to calculate the seismic vulnerability and then a seismic prioritisation~~prioritization~~ index. An engineering-based load and resistance approach, which considers both pullout failure of the first fastener (screw or nail) and pullover failure of the first roof panel, is used to assess the wind vulnerability. Structural components and system resistances (i.e., capacity) are treated as uncertain parameters in the simulations, while gravity and wind load effects (i.e., demand) are considered deterministic (Song, et al. 2019). The CH asset value is considered only in the assessment of ~~the~~ flood vulnerability, which is based on RVS form and it defines the prioritisation~~prioritization~~ index as the average of scores related to different vulnerability factors (e.g., Stephenson and D'Ayala, 2014).

Despotaki et al. (2018) presented a procedure for the evaluation of the seismic risk of CH sites in Europe for prioritisation~~prioritization~~ purposes. The approach exploits the methodology proposed by Lagomarsino (2006)~~, discussed above,~~ for the calculation of baseline vulnerability indices. In order to consider the uniqueness of each asset, vulnerability indices are adjusted based on specific parameters of monuments (e.g., position, state of maintenance or the damage level). The authors applied the proposed procedure to important UNESCO (United Nations Educational, Scientific and Cultural Organization) sites, thus highlighting its feasibility in the vulnerability assessment of large CH building portfolios.

Moratti et al. (2019) proposed a multi-level approach for the seismic assessment of URM churches based on five levels of data collection which lead to three levels of analysis refinement. At each level, performance indices are calculated as ratio of the structural capacity and the seismic demand, both expressed in terms of displacement. At the lowest refinement level, statistical data of church characteristics, which do not require building inspections, are used to perform displacement-based assessments in which structures are approximated through single-degree of freedom (SDoF) systems. The second refinement level requires building inspections in order to define SDoF models for each pier constituting the surveyed churches. In this way, the same methodology developed for the lowest refinement level can be applied also in this case. The highest refinement level requires detailed data in order to build proper global in-plane structural models and local out-of-plane models. The global seismic behaviour can be evaluated by using SDoF models of each pier or multi-degree of freedom (MDoF) models (e.g., equivalent-frame models), which are then used within displacement-based assessment methods in order to apply the same procedure defined for the previous levels. The local out-of-plane behaviour is assessed through kinematic analyses, linear or non-linear one.

Romão and Paupério (2020) presented an approach for the quantification of economic losses related to CH assets damaged by catastrophic natural events. Particularly interesting, for the scope of this study, is the definition of the baseline pre-disaster value of the CH asset which namely corresponds to the asset intangible value. The authors consider four categories (i.e., evidential, historical, aesthetic and communal values) reflecting different levels of CH asset significance (Kerr, 2013). This approach requires only few information about the assets under investigation and then it can be used at portfolio~~-~~-level risk prioritisation/assessment

This brief literature review shows that the few prioritisation~~prioritization~~ approaches which explicitly consider the tangible and intangible value of a CH asset and/or multiple hazards often require detailed information about the structure under investigation~~, since they are based on an explicit loss estimation exercise~~. This can contrast with the nature of risk prioritisation~~prioritization~~ methods at portfolio scale which should require only a small amount of data. Moreover, as discussed in *Section 1*, such procedures are widely ~~used~~ needed in developing countries where specific data ~~are~~ is usually not available, this requiring several simplifying assumptions. The quantification of losses for CH assets is further complicated by the subjective definition of the asset intangible value and the difficulties in assigning a value to ~~their~~ the asset non-market nature.

3 The CHeRiSH framework for the multi-hazard risk prioritisation~~prioritization~~ of cultural heritage assets

~~As discussed above, the~~The multi-hazard risk prioritisation~~prioritization~~ approach proposed in this study is part of a broader project (CHeRiSH) which has different objectives involving civil and structural engineering as well as social science, arts and humanities. From the engineering perspective, the project aims at investigating innovative, non-invasive techniques and tools for CH assets survey and diagnostic, and to develop new methods/models, and their implementation tools for the multi-hazard risk and resilience assessment of CH assets. The main focus of the project is on the exposure and physical vulnerability modelling of CH assets as well as on the prioritisation~~prioritization~~ of resilience-improving solutions for selected assets through multi-criteria decision making. ~~Whereas, from~~ From the social science perspective, the main objectives are related to the promotion of community awareness on the vulnerability of CH assets and the design of disaster risk communication and emergency management campaigns targeted at cultural ~~organizations~~ organisations and local communities.

The overall risk and resilience assessment framework proposed in CHeRiSH has a multi-level structure (Figure 1), consisting of three refinement levels which are directly linked to the amount of available information. The lowest refinement level ~~allows for~~enables an analyst to perform a risk prioritisation~~prioritization~~ of the various CH assets within a given portfolio, while the others two levels can allow for the estimation of the asset structural vulnerability, and ultimately structural risk at a building-specific ~~scale~~level, thus increasing the accuracy of the analysis.

Specifically, the multi-hazard risk prioritisation~~prioritization~~ procedure for CH assets (lowest refinement level) proposed in CHeRiSH can be seen as a five-step procedure, only requiring few basic information about the structures under investigation. These five steps are: 1) data collection through a sidewalk survey (by means of the proposed RVS form); 2) selection of the hazard-intensity level (e.g., for a selected mean return period) for which the prioritisation~~prioritization~~ is needed; 3) calculation of risk prioritisation~~prioritization~~ indices for different hazards; 4) combination of the different single-hazard prioritisation~~prioritization~~ risk indices; and 5) calculation of multi-hazard risk prioritisation~~prioritization~~ indices which accounts for CH asset intangible value~~s~~, and building ranking.

At the second refinement level, data from both the asset interior and exterior are used to build simplified structural models which ~~allow improving~~can be used to enhance the assessment of the structural performances. Since no specific information about materials/details is available at this refinement level, the parameters of the structural models are treated as random variables or assumed based on simulated design.~~–~~ At the highest refinement level structural drawings are required to develop detailed structural models (e.g., finite-element models) for the evaluation of the CH asset performance for various loading conditions. Material test results as well as ~~nondestructive~~non-destructive testing aiming at structural details can also be used for the calibration of numerical models, thus reducing the uncertainty of the results.

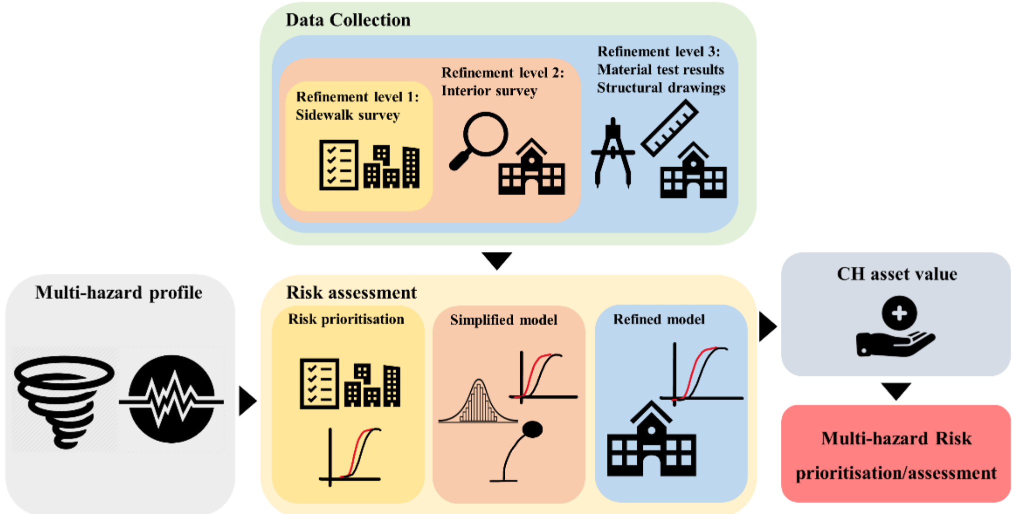


Figure 1: CHeRiSH ~~Multi~~multi-level, multi-hazard risk assessment framework.

3.1 The CHeRiSH Rapid Visual Survey form

The proposed RVS form has been designed in order to account for the specific features of Filipino CH assets, which mainly consist of ~~reinforced concrete (~~RC~~)~~ frames and masonry or mixed structures. It is worth noting, however, that even though the RVS form can be used to collect data related to combined structural typologies, they are not explicitly considered (in terms of scores and weights) in the proposed multi-hazard risk prioritisation framework presented in this study.

~~In fact, a~~According to the Filipino Republic Act no. 10066 (2009), also known as the *National Cultural Heritage Act*, the only "objective" feature which defines a building as a CH asset is the year of construction. Structures which are at least fifty years old can be declared to be a "Heritage House" by the National Historical Commission of the Philippines (NHCP). Differently from the criteria applied by UNESCO ~~(2017)~~(Vecco, 2010) for the definition of CH assets, the Filipino law does not explicitly consider subjective features of the buildings such as the architectonical value and sociocultural factors. Therefore, fairly recent RC frame-type structures, ~~characterized~~ characterised by limited architectural and/or cultural features, are often part of the Filipino CH portfolio. Considering these specific characteristics of the Filipino CH assets, the proposed RVS form has been designed for various structural typologies employing different construction materials and lateral-load resisting systems.

As discussed above, the proposed RVS form (Figure 2) is defined in a multi-level framework. The basic information required for the first level of refinement can be collected by means of a sidewalk survey of the building by trained engineers in approximately 20-30 minutes, depending on the size of the construction. The second level of refinement/accuracy (light grey entries) requires more detailed data on the structure (e.g., presence of non-continuous structural walls, type and quality of roof-to-wall connections, diaphragm typology, among many others) which can be collected only by surveying the building both from its exterior and interior. The third level of refinement/accuracy (dark grey entries) requires material test results and structural drawings in order to calibrate reliable numerical models.

The RVS form is composed of six sections over three pages; it includes various parts related to the general identification and geolocation of the building, its geometric properties (including space for sketching the building's shape and footprint), and its structural characteristics and deficiencies, including the structural typology and the dimensions/details of the main structural members. It is also possible to assign a "Confidence Level" ~~for~~ to each parameter, thus accounting for the degree of uncertainty in the collected data. Special emphasis has been placed on the design of "Vulnerability Factors" and the "Roof Information" sections. The "Vulnerability Factors" section contains a list of vulnerabilities which can be found in the survey of masonry or RC structures. In addition, CH assets in the Philippines are particularly vulnerable to typhoon-induced strong wind, as recent catastrophic events have demonstrated. Since the main collapse mechanisms due to extreme wind and typhoons are related to the failure of roofs (Vickery et al., 2006), the "Roof Information" section requires data about the roof geometry, its structure and connection to the walls, the quality and the conservation of the materials and fasteners. The data collected in the CHeRiSH RVS form are fully compatible with both the Global Earthquake Model (GEM) building taxonomy (Brzev et al., 2013) and the HAZUS model. Hence, existing prioritisation~~prioritization~~ indices based on these two models can also be used within the CHeRiSH framework.

CHeRISH — RAPID VISUAL SURVEY — Cultural Heritage Resilience & Sustainability to multiple Hazards

GENERAL INFORMATION

Date and Time:		Surveyor Name:	
Address:		Nearby Buildings:	[ ] Smaller [ ] Same Height [ ] Taller
No. of Building Users:		GPS Co-Ordinates:	
Construction Year:		Confidence:	[ ] H [ ] M [ ] L
Shape and Composition of the Block:	[ ] Triangular Shape-Synchronic Growth [ ] Elongated Shape-Synchronic Growth [ ] Triangular Shape-Diachronic Growth [ ] Elongated Shape-Diachronic Growth [ ] Bulk Shape-Synchronic Growth [ ] Individual Buildings [ ] Bulk Shape-Diachronic Growth		
Position in Block:	[ ] Corner [ ]Mid-block [ ]End-block [ ]Isolated [ ]Other:		
Type of Survey:	[ ] Desktop Review [ ] Exterior [ ] Part. Interior [ ] Interior		

BUILDING INFORMATION

No. of Stories:	
Storey Height (m):	
Average Height of Upper Horizontal Spandrel (m):	
Connection of the Walls at the Edges (Exterior):	[ ] Adequate [ ] Poor
Wall Openings Max. Dim. $(m \times m)$:	
Wall Openings Total Area (m^2):	
Opening Layout:	[ ] Opening with Vertical Alignment at Both the Edges of Façade [ ] Openings with Vertical Alignment at an Edge of the Façade [ ] Central Column of Opening, Vertically Aligned
Opening Alignment:	[ ] Regular [ ] Medium [ ] Irregular
Dim. Between Int. Structural Wall $(m \times m)$:	

Simple Building Plan

Max. Thickness Ext. Walls (m):		Min. Thickness Ext. Walls (m):	
Max. Thickness Int. Walls (m):		Min. Thickness Int. Walls (m):	
Non-Continuous Structural Wall:	[ ] Yes [ ] No ⟶ Position:		
Plan Regularity:	[ ] Regular [ ] Medium [ ] Irregular	Confidence:	[ ] H [ ] M [ ] L
Height Regularity:	[ ] Regular [ ] Medium [ ] Irregular	Confidence:	[ ] H [ ] M [ ] L
Drawings:	[ ] Yes [ ] No [ ] Structural [ ] Architectural ⟶ File Name:		

ROOF INFORMATION		Unk	Confidence
Type:	[ ] Flat [ ] Mono Pitch [ ] Multi Pitch [ ] Gable	[ ]	[ ] H [ ] M [ ] L
Truss Material:	[ ] RC Slab [ ] Timber [ ] Steel [ ] Other	[ ]	[ ] H [ ] M [ ] L
Slope (°):	Soffit Width (m): Mean Roof Height (m):	[ ]	[ ] H [ ] M [ ] L
Panel Material:	[ ] Timber [ ] Steel [ ] Other Thickness (mm):	[ ]	[ ] H [ ] M [ ] L
Fastener Type:	[ ] Screw [ ] Nail [ ] Other	[ ]	[ ] H [ ] M [ ] L
No. of Purlins:	No. of Fasteners Per Purlin Bay:	[ ]	[ ] H [ ] M [ ] L

CHeRISH — RAPID VISUAL SURVEY — Cultural Heritage Resilience & Sustainability to multiple Hazards

GENERAL INFORMATION

Time:		Date:		Surveyor Name:	
Building Address:		Nearby Buildings:	[ ] Smaller [ ] Same Height [ ] Taller		
No. of Building Users:		GPS Co-Ordinates:	Lat:	Long:	Elev.:
Construction Year:		Confidence:	[ ] H [ ] M [ ] L		
Shape and Composition of the Block:	[ ] Triangular Shape-Synchronic Growth [ ] Triangular Shape-Diachronic Growth [ ] Bulk Shape-Synchronic Growth [ ] Bulk Shape-Diachronic Growth	[ ] Elongated Shape-Synchronic Growth [ ] Elongated Shape-Diachronic Growth [ ] Individual Buildings			
Position in Block:	[ ] Corner [ ]Mid-block [ ]End-block [ ]Isolated [ ]Other:				
Type of Survey:	[ ] Desktop Review [ ] Exterior [ ] Part. Interior [ ] Interior				

BUILDING INFORMATION

No. of Stories:	
Storey Height (m):	
Average Height of Upper Horizontal Spandrel (m):	
Connection of the Walls at the Edges (Exterior):	[ ] Adequate [ ] Poor
Wall Openings Max. Dim. $(m \times m)$:	
Wall Openings Total Area (m^2):	
Opening Layout:	[ ] Opening with Vertical Alignment at Both the Edges of Façade [ ] Openings with Vertical Alignment at an Edge of the Façade [ ] Central Column of Opening, Vertically Aligned
Façade Regularity:	[ ] Regular [ ] Medium [ ] Irregular
Dim. Between Int. Structural Wall $(m \times m)$:	

Simple Building Plan

Max. Thickness Ext. Walls (m):		Min. Thickness Ext. Walls (m):	
Max. Thickness Int. Walls (m):		Min. Thickness Int. Walls (m):	
Non-Continuous Structural Wall:	[ ] Yes [ ] No ⟶ Position:		
Plan Regularity:	[ ] Regular [ ] Medium [ ] Irregular	Confidence:	[ ] H [ ] M [ ] L
Height Regularity:	[ ] Regular [ ] Medium [ ] Irregular	Confidence:	[ ] H [ ] M [ ] L
Drawings:	[ ] Yes [ ] No [ ] Structural [ ] Architectural? ⟶ Attached File Name:		

ROOF INFORMATION		Unk	Confidence
Type:	[ ] Flat [ ] Mono Pitch [ ] Multi Pitch [ ] Gable	[ ]	H M L
Slope (°):	Soffit Width (m): Mean Roof Height (m):	[ ]	H M L
Truss (Inc. Purlin) Material:	[ ] RC Slab [ ] Timber [ ] Steel [ ] Other	[ ]	H M L
Panel Material:	[ ] Timber [ ] Steel [ ] Other Thickness (mm):	[ ]	H M L
Fastener Type:	[ ] Screw [ ] Nail [ ] Other	[ ]	H M L
No. of Purlins:	No. of Fasteners Per Purlin Bay:	[ ]	H M L

Fastener Dia. (mm):	Fastener Penetration (mm):	[ ]	H M L
Roof-Wall Connection:	[ ] Simply Supported [ ] Pinned [ ] Fixed Support	[ ]	H M L
Roof-Wall Fastener:	[ ] Metal Plate Connector [ ] Single Hurricane Tie [ ] Toe Nails [ ] Double Hurricane Tie	[ ]	H M L
Ornaments Type:	Material: Dimension $(m \times m)$:	[ ]	H M L

STRUCTURAL INFORMATION		Unk	Confidence
Material of Lateral Resisting System:	[ ] Reinforced Concrete [ ] Masonry [ ] Timber [ ] Steel [ ] Other:	[ ]	H M L
Type of Lateral Load Resisting System:	[ ] Frame Masonry [ ] Dual System [ ] Shear Wall [ ] Confined Masonry [ ] Bracing [ ] Reinforced [ ] Other:	[ ]	H M L
Structural Condition:	[ ] Poor / Deteriorated [ ] Good / Fair [ ] Excellent / New	[ ]	H M L
Environmental Exposure:	[ ] Dry Environment [ ] Aggressive Chemical Environment [ ] Moisture or Wetting [ ] Saturated Salt Air	[ ]	H M L
Foundation Type:	[ ] Deep [ ] Superficial [ ] Not Accessible Note:	[ ]	H M L
Diaphragm Type:	[ ] Timber [ ] Concrete	[ ]	H M L
Load Distribution:	[ ] One-Way Spanning [ ] Two-Way Spanning	[ ]	H M L
Diaphragm-Wall Connection:	[ ] Simply Supported [ ] Steel Bars [ ] RC Ring Beam	[ ]	H M L
Retrofitting:	[ ] Yes [ ] No Description:	[ ]	H M L
Modifications:	[ ] Yes [ ] No ⟶ Position: [ ] Addition of Stories [ ] Extension of Plan [ ] Wall Opening Framing [ ] Steel Frame Opening ⟶ Position:	[ ]	H M L
Vulnerability Factors:	[ ] Balconies [ ] Parapet [ ] Gable [ ] Pounding [ ] Mass Irregularity [ ] Built on Slope [ ] Built on Stilts [ ] Other:	[ ] Short Column [ ] Strong Beam-Weak Column [ ] Soft Storey [ ] Roof Thrust ⟶ Length x Height (m): [ ] Vaults / arches ⟶ Length x Height (m): [ ] Connection Between Orthogonal Wall (Interior): H M L [ ] Existing Cracks ⟶ Info:	

MASONRY

Masonry Type:	[ ] Chaotic Stone [ ] Masonry with Hewn Blocks [ ] Hollow Brick [ ] Regular Sized Stone [ ] Soft Stone Block [ ] Squared Stone Blocks [ ] Solid Brick Masonry and Lime Mortar [ ] Hollow Brick with Cement Mortar [ ] Hollow Brick without Mortar in Vertical Joints [ ] Concrete Blocks or Expanded Clay Blocks [ ] Concrete Hollow Blocks	[ ]	H M L
Mortar Type & Thickness:	[ ] Cement [ ] Mud [ ] Mud with Cement [ ] Lime [ ] Lime with Bricks [ ] Other: Thickness (mm):	[ ]	H M L

Maintenance:	[ ] Low [ ] Medium [ ] High	[ ]	H M L
Water Infiltration:	[ ] Low [ ] Medium [ ] High	[ ]	H M L
Mortar Loss:	[ ] Low [ ] Medium [ ] High	[ ]	H M L
Transversal Connection Quality:	[ ] Low [ ] Medium [ ] High	[ ]	H M L
Average Size of the Units (mm):			
Wall Tie Presence:	[ ] Yes [ ] No	[ ]	H M L
No. of Leaves:	[ ] Single-Leaf [ ] Multi-Leaf No. of Header Courses:	[ ]	H M L
Wall Core:	[ ] Yes [ ] No Quality: [ ] Poor [ ] Thick [ ] Good	[ ]	H M L
Masonry Improvements:	[ ] Mixture Injection [ ] Concrete Jacketing	[ ]	H M L
Material Test Results:	Attached File Name:	[ ]	H M L

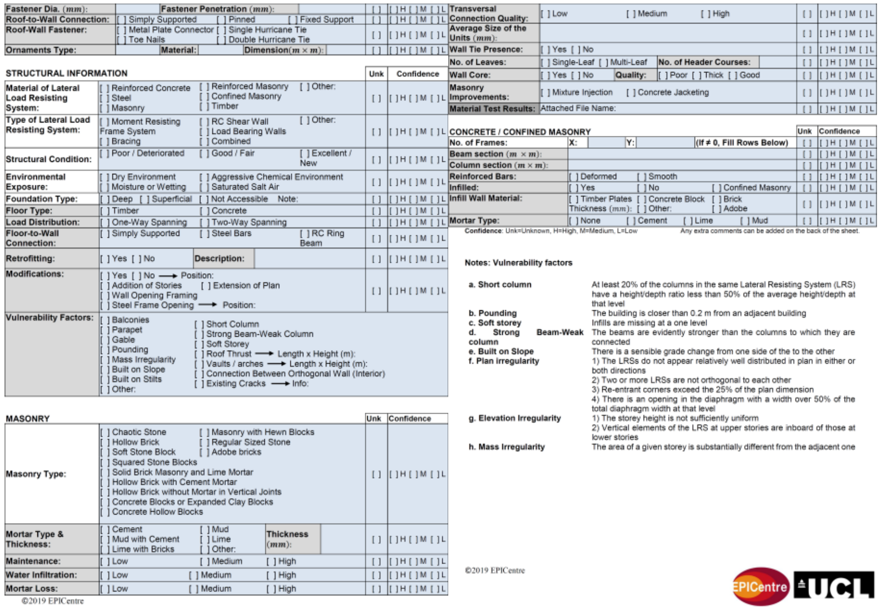
CONCRETE / CONFINED MASONRY

No. of Frames:	X: Y: (If ≠ 0, Fill Rows Below)	[ ]	H M L
Beam section $(m \times m)$:		[ ]	H M L
Column section $(m \times m)$:		[ ]	H M L
Reinforced Bars:	[ ] Deformed [ ] Smooth	[ ]	H M L
Infilled:	[ ] Yes [ ] No [ ] Confined Masonry	[ ]	H M L
Infill Wall Material:	[ ] Timber Plates [ ] Concrete Block [ ] Brick Thickness (mm): [ ] Other: [ ] Adobe	[ ]	H M L
Mortar Type:	[ ] None [ ] Cement [ ] Lime [ ] Mud	[ ]	H M L

Confidence: Unk=Unknown, H=High, M=Medium, L=Low — Any extra comments can be added on the back of the sheet.

Notes: Vulnerability factors

a. Short column	At least 20% of the columns in the same Lateral Resisting System (LRS) have a height/depth ratio less than 50% of the average height/depth at that level
b. Pounding	The building is closer than 0.2 m from an adjacent building
c. Soft storey	Infills are missing at a one level
d. Strong Beam-Weak column	The beams are evidently stronger than the columns to which they are connected
e. Built on Slope	There is a sensible grade change from one side of the to the other
f. Plan irregularity	1) The LRSs do not appear relatively well distributed in plan in either or both directions 2) Two or more LRSs are not orthogonal to each other 3) Re-entrant corners exceed the 25% of the plan dimension 4) There is an opening in the diaphragm with a width over 50% of the total diaphragm width at that level
g. Elevation Irregularity	1) The storey height is not sufficiently uniform 2) Vertical elements of the LRS at upper stories are inboard of those at lower stories
h. Mass Irregularity	The area of a given storey is substantially different from the adjacent one



		Unk	Confidence
Fastener Dia. (mm):	Fastener Penetration (mm):	[ ]	[ ] H [ ] M [ ] L
Roof-to-Wall Connection:	[ ] Simply Supported [ ] Pinned [ ] Fixed Support	[ ]	[ ] H [ ] M [ ] L
Roof-Wall Fastener:	[ ] Metal Plate Connector [ ] Single Hurricane Tie [ ] Toe Nails [ ] Double Hurricane Tie	[ ]	[ ] H [ ] M [ ] L
Ornaments Type:	Material: Dimension(m × m):	[ ]	[ ] H [ ] M [ ] L

STRUCTURAL INFORMATION

		Unk	Confidence
Material of Lateral Load Resisting System:	[ ] Reinforced Concrete [ ] Steel [ ] Masonry [ ] Reinforced Masonry [ ] Confined Masonry [ ] Timber [ ] Other:	[ ]	[ ] H [ ] M [ ] L
Type of Lateral Load Resisting System:	[ ] Moment Resisting Frame System [ ] Bracing [ ] RC Shear Wall [ ] Load Bearing Walls [ ] Combined [ ] Other:	[ ]	[ ] H [ ] M [ ] L
Structural Condition:	[ ] Poor / Deteriorated [ ] Good / Fair [ ] Excellent / New	[ ]	[ ] H [ ] M [ ] L
Environmental Exposure:	[ ] Dry Environment [ ] Moisture or Wetting [ ] Aggressive Chemical Environment [ ] Saturated Salt Air	[ ]	[ ] H [ ] M [ ] L
Foundation Type:	[ ] Deep [ ] Superficial [ ] Not Accessible Note:	[ ]	[ ] H [ ] M [ ] L
Floor Type:	[ ] Timber [ ] Concrete	[ ]	[ ] H [ ] M [ ] L
Load Distribution:	[ ] One-Way Spanning [ ] Two-Way Spanning	[ ]	[ ] H [ ] M [ ] L
Floor-to-Wall Connection:	[ ] Simply Supported [ ] Steel Bars [ ] RC Ring Beam	[ ]	[ ] H [ ] M [ ] L
Retrofitting:	[ ] Yes [ ] No Description:	[ ]	[ ] H [ ] M [ ] L
Modifications:	[ ] Yes [ ] No ⟶ Position: [ ] Addition of Stories [ ] Extension of Plan [ ] Wall Opening Framing [ ] Steel Frame Opening ⟶ Position:	[ ]	[ ] H [ ] M [ ] L
Vulnerability Factors:	[ ] Balconies [ ] Parapet [ ] Gable [ ] Pounding [ ] Mass Irregularity [ ] Built on Slope [ ] Built on Stilts [ ] Other: [ ] Short Column [ ] Strong Beam-Weak Column [ ] Soft Storey [ ] Roof Thrust ⟶ Length x Height (m): [ ] Vaults / arches ⟶ Length x Height (m): [ ] Connection Between Orthogonal Wall (Interior) [ ] Existing Cracks ⟶ Info:		

MASONRY

		Unk	Confidence
Masonry Type:	[ ] Chaotic Stone [ ] Hollow Brick [ ] Soft Stone Block [ ] Masonry with Hewn Blocks [ ] Regular Sized Stone [ ] Adobe bricks [ ] Squared Stone Blocks [ ] Solid Brick Masonry and Lime Mortar [ ] Hollow Brick with Cement Mortar [ ] Hollow Brick without Mortar in Vertical Joints [ ] Concrete Blocks or Expanded Clay Blocks [ ] Concrete Hollow Blocks	[ ]	[ ] H [ ] M [ ] L
Mortar Type & Thickness:	[ ] Cement [ ] Mud with Cement [ ] Lime with Bricks [ ] Mud [ ] Lime [ ] Other: Thickness (mm):	[ ]	[ ] H [ ] M [ ] L
Maintenance:	[ ] Low [ ] Medium [ ] High	[ ]	[ ] H [ ] M [ ] L
Water Infiltration:	[ ] Low [ ] Medium [ ] High	[ ]	[ ] H [ ] M [ ] L
Mortar Loss:	[ ] Low [ ] Medium [ ] High	[ ]	[ ] H [ ] M [ ] L
Transversal Connection Quality:	[ ] Low [ ] Medium [ ] High	[ ]	[ ] H [ ] M [ ] L
Average Size of the Units (mm):		[ ]	[ ] H [ ] M [ ] L
Wall Tie Presence:	[ ] Yes [ ] No	[ ]	[ ] H [ ] M [ ] L
No. of Leaves:	[ ] Single-Leaf [ ] Multi-Leaf No. of Header Courses:	[ ]	[ ] H [ ] M [ ] L
Wall Core:	[ ] Yes [ ] No Quality: [ ] Poor [ ] Thick [ ] Good	[ ]	[ ] H [ ] M [ ] L
Masonry Improvements:	[ ] Mixture Injection [ ] Concrete Jacketing	[ ]	[ ] H [ ] M [ ] L
Material Test Results:	Attached File Name:	[ ]	[ ] H [ ] M [ ] L

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CONCRETE / CONFINED MASONRY

		Unk	Confidence
No. of Frames:	X: Y: (If ≠ 0, Fill Rows Below)	[ ]	[ ] H [ ] M [ ] L
Beam section (m × m):		[ ]	[ ] H [ ] M [ ] L
Column section (m × m):		[ ]	[ ] H [ ] M [ ] L
Reinforced Bars:	[ ] Deformed [ ] Smooth	[ ]	[ ] H [ ] M [ ] L
Infilled:	[ ] Yes [ ] No [ ] Confined Masonry	[ ]	[ ] H [ ] M [ ] L
Infill Wall Material:	[ ] Timber Plates [ ] Concrete Block [ ] Brick Thickness (mm): [ ] Other: [ ] Adobe	[ ]	[ ] H [ ] M [ ] L
Mortar Type:	[ ] None [ ] Cement [ ] Lime [ ] Mud	[ ]	[ ] H [ ] M [ ] L

Confidence: Unk=Unknown, H=High, M=Medium, L=Low — *Any extra comments can be added on the back of the sheet.*

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Figure 2: CHeRiSH RVS form. **The full RVS form in its original 3 x A4-size pages is available online as supplemental material to this paper.**

3.1.1 The use of new technologies for CH assets survey and diagnostic

CH assets located in highly-populated cities are deeply integrated within the urban fabric and they may host private and public activities. This ~~complicates and~~can slows down survey campaigns because it limits the possibility to access areas of the ~~construction~~ building and to properly collect data. Moreover, the time available to carry out the survey is usually limited because of the high costs involved per person-hour. In order to improve the amount and quality of the data collected on site without increasing the number of personnel involved, new technologies ~~should~~ can be effectively utilised during fieldworks. Indeed, one of the objectives of the CHeRiSH project was to test the feasibility of applying new technologies for the survey of CH assets. In particular, omnidirectional cameras, thermal cameras, drones, photogrammetry and Building Information Modeling (BIM) have been extensively used during the fieldwork discussed in *Section 4* of this paper.

Omni-directional cameras (also known as 360° cameras) are devices that have two wide angle (> 85°) fisheye lenses mounted back-to-back, facing in opposite directions that each are able to photograph 180° of a scene. The camera can then produce two unstitched 180° pictures which can also be stitched together to form one 360° (equirectangular) picture. 360° pictures can be used during a desktop review to build 3D point clouds of the asset interior, to find lost data and to assess the presence, type, and location of non-structural elements. Interior 3D point clouds can be used to determine distances and heights of the structural members which cannot be directly acquired in the field because of the activities hosted by the surveyed buildings. Non-structural elements can be a source of vulnerability, so their presence must be considered during the definition of resilience-enhancing strategies.

Similarly, the collection of reliable measurements of the building exterior is a challenging task, especially in densely populated cities. Indeed, car traffic, people and temporary obstacles prevent the architectural survey. Therefore, as in the case of interior measurements, exterior point clouds can be analysed during a desktop review, allowing a more accurate definition of the building dimensions. Exterior point clouds can be built by using photogrammetry technology (e.g., Aicardi et al., 2018) which allows transforming pictures, such as the ones taken by smartphones, into measurable objects.

In addition, Tthe use of a quadcopter drone is a personnel multiplier and can further help an analysis overcominge various building access issues that are frequently encountered on site. Because of the unique vantage point that they offerSpecifically, drones can have the most influential impact in the quality and quantity of data collected for the roof survey. It is worth noting that post-event surveys in the Philippines and around the world reveals that most economic loss in high wind-hazard areas are related to the breach of the building envelope, particularly roofs. The breach of a building envelope typically includes roof panel uplift, roof-to-wall connection failure, roof system damage, and rupture of window and door glasses due to excessive pressure or missile impact. With the roof heavily damaged or removed, walls may become unstable without sufficient lateral support and can collapse. Hence, during strong typhoons, nonengineered roofs built with low quality materials (typical of CH assets) and showing heaving material degradation (due to aging) are highly vulnerable to wind uplift and are the main concern here. The collection of data on roof characteristic is usually very difficult because of their inaccessibility. The data required for the calculation of the wind prioritisationprioritization index defined in the currentthis study can be assessed much quicker with use of by using a drone rather than through direct- access to/inspection of the roofvisualisation by accessing the building. The use of drones is then particularly useful to carry out a reliable roof inspection and build accurate numerical models for wind fragility estimation.

Finally, Tthe quality and typology of the masonry characterizing characterising a given asset, and the diaphragm characteristics (e.g., its orientation) are essential data needed even at the first refinement level of the proposed framework. Due to the activities hosted by the considered CH assets and their architectural value, specific (invasive) inspection tests cannot be performed. Non-invasive techniques such as thermal cameras may play an important role for the collection of this information. Thermal cameras allow one to detect infrared energy (heat) and converting it into an electronic signal, which is then processed to produce a thermal image. Since heat sensed by a thermal camera can be very precisely measured and materials are characterized characterised by different thermal properties (e.g., emissivity coefficients), their presence within the structure can be easily detected by just taking a picture. However, the use of thermal cameras is strictly related to the presence of thermal flux within the surveyed structural element. If the system is in thermal equilibrium, the different thermal characteristics of the materials are not highlighted and then their presence cannot be properly detected.

The use of a quadcopter drone is a personnel multiplier and can overcome building access issues that are frequently encountered on site. Because of the unique vantage point that they offer, drones can have the most influential impact in the quality and quantity of data collected for the roof survey. It is worth noting that post-event surveys in the Philippines and around the world reveals that most economic loss in high wind-hazard areas are related to the breach of the building envelope. The breach of a

~~building envelope typically includes roof panel uplift, roof-to-wall connection failure, roof system damage, and rupture of window and door glasses due to excessive pressure or missile impact. With the roof heavily damaged or removed, walls may become unstable without sufficient lateral support and can collapse. Hence, during strong typhoons, nonengineered roofs built with low quality materials (typical of CH assets) and showing heaving material degradation (due to aging) are highly vulnerable to wind uplift and are the main concern here. The collection of data on roof characteristic is usually very difficult because of their inaccessibility. The data required for the calculation of the wind prioritization index defined in the current study can be assessed quicker with use of a drone rather than through direct visualisation by accessing the building. The use of drones is then particularly useful to carry out a reliable roof inspection and build accurate numerical models for wind fragility estimation.~~

The use of new technologies, as described above, drastically increases the stream and amount of data/information which can become prohibitive to manage. Therefore, a suitable BIM platform is currently under development within the CHeRiSH project. The platform is designed to store all the data collected during the fieldwork in Iloilo City, and it will allow ~~the creation~~an analysist to create ~~of~~ accurate 3D models (architectural and structural ones) of the surveyed buildings. This can be achieved by exploiting the interior and exterior point clouds created respectively by using the photogrammetry and omnidirectional cameras. The BIM platform can also play a crucial role to access the vulnerability data of the surveyed CH assets and to manage resilience-enhancing strategies.

3.2 The seismic risk prioritisation~~prioritization~~ index

In this study, the INSPIRE index (Gentile et al., 2019) for the seismic risk prioritisation~~prioritization~~ of RC ~~constructions~~ buildings is extended to URM buildings. The need for this extension is justified by the composition of the Filipino CH portfolio, which counts different structural typologies, including URM buildings. The INSPIRE index, and then the proposed one for CH assets (I_S), is an empirical proxy for the relative seismic risk of various buildings within a given building portfolio. It consists of two components: a baseline score (I_{BL}) and a performance modifier (ΔI_{PM}), which are finally summed up to obtain the total seismic risk index (Eq.1).

$$I_S = I_{BL} + \Delta I_{PM}, \qquad (1)$$

The extension of the INSPIRE index to include URM buildings has required the definition of a proper performance modifier, as described in detail in this section. However, guidance on the computation of the RC-building performance modifier is also provided, because of the high occurrence of this structural typology within the analysed CH portfolio (*Section 4*).

The calculation of the baseline score is based on the fragility curves available in the HAZUS model (Kircher et al., 2006), which represent an ~~harmonized~~ harmonised and transparent framework for the multi-hazard fragility/vulnerability/risk assessment of a wide range of structures. The use of the HAZUS model as a starting point for the definition of proposed seismic risk prioritisation~~prioritization~~ index is further justified by the fact that several countries around the world, including the Philippines, have adopted seismic provisions which are consistent with the recommendations of the Uniform Building Code 1994 (UBC, ICBO, 1994). In fact, this code is used as a benchmark to define four seismic *code levels* in the HAZUS framework. The four *code levels* are: high, moderate, low and pre-code (not seismically designed) level. The first three levels are defined with regard to the provisions in UBC (ICBO, 1994) for seismic zone 4, 2b and 1, respectively. Indeed, the National Structural Code of the Philippines (NSCP, 2015) is the primary design code in the country, providing guidance to civil and structural engineers on the design and assessment of buildings, and any other structures since its 1st edition in 1972. Table 1 below shows the history of the NSCP. The post-2001 NSCP versions are all based on the 1997 UBC, and earlier versions were similarly based on previous editions of the UBC, as shown in the Table 1, allowing the proposed mapping with the HAZUS code levels. Based on the data collected during the survey, four separate vintages can be identified: post-2001 (which includes also post-2010, i.e., all the building designed consistently with the UBC 1997), 1991–2001, 1971-~~1970~~1990, and Pre-1970 (Table 2). ~~In this case the analysis of the results~~Results from the onsite surveys often~~,~~ show~~s~~ that the actual construction practice ~~does not seem to~~often does not closely follow the design plans and code specifications; in those cases,~~,~~ the code compliance for each design vintage can be downgraded by one level for the analysis.

The HAZUS fragility curves express the seismic performance of archetype buildings (for a given structural type) which are classified based on four parameters: material (*Mat*), basic structural system (*BSS*), building *Height* and seismic *Code Level*. Such fragility curves are log~~-~~normal cumulative distribution functions (CDFs) expressing the conditional probability that the given structure will reach or exceed a pre-defined damage state (DS) given the hazard intensity measure (IM). The HAZUS-model fragility curves are defined in terms of median (μ) and dispersion (β; i.e., the logarithmic standard deviation) parameters ~~for~~ in terms of different IMs, including the peak ground acceleration (PGA), and for various DSs, i.e., slight, moderate, extensive and complete damage (see Kircher et al., 2006 for details).

Table 1: Evolution of Seismic Codes in the Philippines

Philippines Design Code (Edition)	Basis for general and earthquake loading provisions
NBCP 1972 (1st edition; 2nd printing in 1977) National Building Code of the Philippines	UBC 1970
NBCP 1982 (2nd edition)	UBC 1978
NSCP 1987 (3rd edition) National Structural Code of the Philippines	UBC 1985
NSCP 1992 (4th edition, Volume 1 – Buildings, Towers, and Other Vertical Structures; Volume 2 for Bridges published in 1997)	UBC 1988
NSCP 2001 (5th edition, Volume 1 – Buildings, Towers, and Other Vertical Structures)	UBC 1997 - inclusion of Active Fault Maps from PHIVOLCS
NSCP 2010 (6th edition, Volume 1 – Buildings, Towers, and Other Vertical Structures)	UBC 1997 - inclusion of Active Fault Maps from PHIVOLCS
NSCP 2015 (7th edition, Volume 1 – Buildings, Towers, and Other Vertical Structures)	UBC 1997 - updated Active Fault Maps presented by region

Table 2: HAZUS Building Seismic Design Level Classifications

Construction data	FEMA HAZUS code compliance assignment
Post-2001	Moderate code (for NSCP 2001 – 2010)
1991–2001	Low code (for NSCP 1992)
1970-1990	Pre-code (for NSCP 1972 – 1987)

Pre-1970	No Code

The calculation of the baseline score requires the selection of a target DS, a set of building classes (~~characterized~~ characterised by a combination of *Mat*, *BSS*, *Height* and *Code Level*), and one or more hazard levels (in terms of the considered IM). Such hazard level must be selected based on the seismicity of the considered building portfolio/geographic area and the considered performance objective. The DS exceeding probability for each considered building class can thus be computed for the considered IM level(s). Specifically, considering PGA as the reference IM, the building basic parameters are mapped into the exceeding probability of the selected DS (‘Extensive damage state’ or DS_3 in this study) conditional to the PGA ~~value~~level, as in Eq. 2.

$$P_{HAZUS} = P(DS \geq DS_3 | Mat, BSS, Code\ Level, Height, PGA) \quad (2)$$

Baseline scores are then calculated in order to be proportional to such exceeding probabilities after a rescaling in the range [1 %, 50 %] based on the minimum and maximum DS exceeding probability in the complete (non-filtered) HAZUS database, as follows:

$$I_{BL} = \left(\frac{50-1}{P_{HAZUS,max} - P_{HAZUS,min}}\right)\left(P_{HAZUS} - P_{HAZUS,min}\right) + 1. \quad (3)$$

In Eq. 3, $P_{HAZUS,max}$ and $P_{HAZUS,min}$ are the maximum and minimum DS exceeding probability in the HAZUS database for the selected level(s) of PGA, while P_{HAZUS} is the DS exceeding probability of the considered building, for the chosen level of PGA. Figure 3 shows the fragility curve set related to the ~~Extensive~~ extensive ~~Damage~~ damage state ~~-~~for RC and URM buildings adopted in this study. The ~~Extensive~~ extensive ~~Damage~~ damage state is arbitrarily selected for illustrative purposes in this study and it is mainly related to the life~~-~~-safety performance objective; ~~, but~~ other DSs can be key to ensure the integrity of CH assets and can be considered in the proposed framework. ~~The aim of the study is to assess the validity of the prioritisationprioritization framework in the worst-case scenario, this justifies the choice of the Extensive Damage state.~~

The performance modifier (ΔI_{PM}) represents the perturbation of the baseline score due to the presence of vulnerability factors. Its calculation requires the definition of secondary parameters selected with respect to the construction features of the investigated portfolio in order to complement the information in the HAZUS fragility curves. Therefore, the baseline score provides the (conditional) seismic risk of a given building class, while the secondary parameters are related to building-specific vulnerability factors.

In its original version (Gentile et al., 2019), the performance modifier is defined as the weighted summation of scores ($SCORE_{seismic}$) which describe different alternatives of each secondary parameter and which are defined on a uniform partitioning of the range [0%, 100%], typically based on engineering judgement. The weights (w_{SP}) are needed to reflect the relative importance of the considered secondary parameters, which affect the seismic behaviour of buildings in different ways. In this work, the AHP (Saaty, 1980) is used to calibrate such weights. This process allows an analyst to have a rational and mathematically consistent assignment of the weights: starting from expert judgements on every possible pairwise comparison of the secondary parameters, collected into a so-called decision matrix, the AHP allows one to obtain the values of the weights by solving an eigenvalues problem.

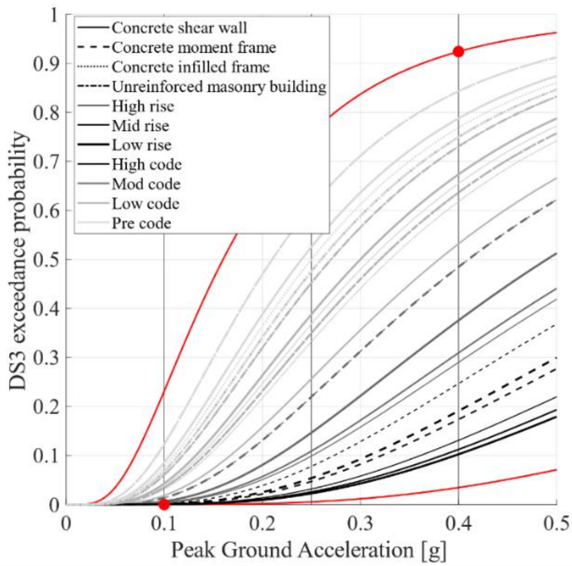


Figure 3:HAZUS fragility curve database related to DS$_3$ the (Extensive Damage limit sState) for RC and URM buildings.

In particular, the seismic vulnerability assessment of URM buildings requires consideration of the quality of the material (e.g., Borri et al., 2015), the out-of-plane local mechanisms (e.g., Sorrentino et al., 2017; D'Ayala and Speranza, 2013) and global (the in-plane) behaviour (e.g., Lagomarsino et al., 2013; Novelli et al., 2015). These factors, together with the presence of façade ornaments, have been considered as macro-categories for the definition of the URM-building performance modifier. According to the scientific literature (e.g., Borri et al., 2015), the *Material Quality*, which expresses the quality of the masonry, strongly affects the seismic response of the structure. The *Material Quality* is thus calculated based on the *Masonry Typology* (e.g., Rubble uncoursed Chaotic stones, Solid brick masonry with lime mortar, Concrete blocks) and the *Masonry Degradation*. If the *Material Quality* is not sufficiently high, the structure cannot develop the so-called out-of-plane local mechanisms. Therefore, this parameter must be considered more important than the others. The *Local Out-of-plane Behaviour* is the second most important macro-category. Indeed, if out-of-plane local mechanisms are not avoided, the structure cannot behave as a unique fabric (e.g., Sorrentino et al., 2017). When the material quality is sufficient and the out-of-plane local mechanisms prevented, then the *Global In-plane Behaviour* must be assessed (e.g., Lagomarsino et al., 2013) and of course it is more important than the presence of non-structural *Façade Ornaments* (Figure 3). The expert judgments (Table A.1) used in this study for the calibration of the macro-category weights ($w_{MC,m}$) through the AHP reflect these considerations. Clearly, the decision matrix adopted in this study reflects the characteristics of the Filipino CH assets and the expert opinion of the authors (academic and professional engineers across the UK and the Philippines); it should be further calibrated before the entire procedure can be applied for the analysis of different building portfolio.

The secondary parameters collected within each macro-category have been selected based on the fundamental rules of masonry structure design (e.g., Heyman, ~~2014~~1997; Paulay and Priestley, 1992) and the commonly observed post-earthquake damage on URM structures (e.g., Fiorentino et al., 2018; Mazzoni et al., 2018~~…~~). For this reason, parameters related to the geometry and the regularity of the façade (*Opening Layout*, *Wall Slenderness*, ~~*Façade Regularity*~~*Opening Alignment* and *Opening Area*) as well as those related to connections (*Wall-to-Wall connection*, ~~*Wall*~~*Floor-to-Wall*~~*-to-Diaphragm*~~ *connection* and *Wall-to-Roof connection*) are considered for the definition of the ~~*Local*~~ *Out-of-plane Behaviour*. Indeed, it is well known that the activation of out-of-plane ~~local~~ mechanisms is strictly linked to the geometry of the piers (i.e., *Opening Layout*), which is also determined by the position of the openings (i.e., *Opening Alignment*), and the connection with orthogonal walls, diaphragms and roof (D'Ayala, 2005). In this study, the presence/quality of connections has been valued more important than the geometry/regularity of the facades, as shown in Table A.2. This is ~~due to the fact that~~because the Filipino CH portfolio is characterised by buildings with regular opening layouts but various diaphragm typologies, so a proper prioritisation~~prioritization~~ scheme can be achieved by using the proposed judgments. The dimension of the piers, which is linked to the *Opening Layout* and the *Opening Alignment*, affect both the out-of-plane and the in-plane behaviours (e.g., Parisi and Augenti, 2013) of the URM building resisting members. However, in the proposed approach, these secondary parameters are considered only in the ~~*Local*~~*In-plane Behaviour* component to avoid counting their effect twice.

The regularity of the building (*Plane Shape* and *Storey Height Uniformity*) and the presence of vulnerability factors (*Added Storeys*, *Pounding* and *Unfavourable Soil*) are used to quantify the ~~*Global*~~ *In-plane Behaviour* of URM buildings. The regularity of the Filipino CH assets leads to assign greater importance to vulnerability factors, such as *Pounding* and *Unfavourable Soil*, rather than the others thus achieving a relatively more accurate prioritisation~~prioritization~~ scheme (Table A.3).

Table 3 provides guidance on the selection of the alternatives for the calculation of the URM building performance modifier. The performance modifier can be finally calculated as in Eq. 4,

$$\Delta I_{PM} = \frac{1}{2}\sum_{m=1}^{M} w_{MC,m} \sum_{n=1}^{N_m} w_{SP,n} SCORE_{seismic;m,n}, \tag{4}$$

where M is the total number of macro-categories, N_m is the number of secondary parameters within the m-th macro-category and the subscript n indicates the considered secondary parameter.

The secondary parameters for the calculation of the RC structure performance modifier are selected according to Gentile et al. (2019). Having no macro-categories in this case, the weights $w_{MC,m}$ in Eq. 4 are assumed equal to 1, while the secondary parameters weights $w_{SP,n}$ are calibrated through the AHP to reflect the expert judgments indicated in Table A.4; see Gentile et al. (2019) for a critical discussion on the assumptions made here. These parameters express the *Preservation Condition* of the material, the regularity of the structure (*Plane Shape*, *Storey Height Uniformity* and *Added Storeys*), the presence of vulnerability factors (*Infills at Ground Storey*, *Short Column* and *Pounding*) and the soil conditions (*Unfavourable Soil*); these parameters can capture various vulnerability factors observed in post-earthquake damage surveys of RC building (e.g., De Luca et al., 2018).~~.~~

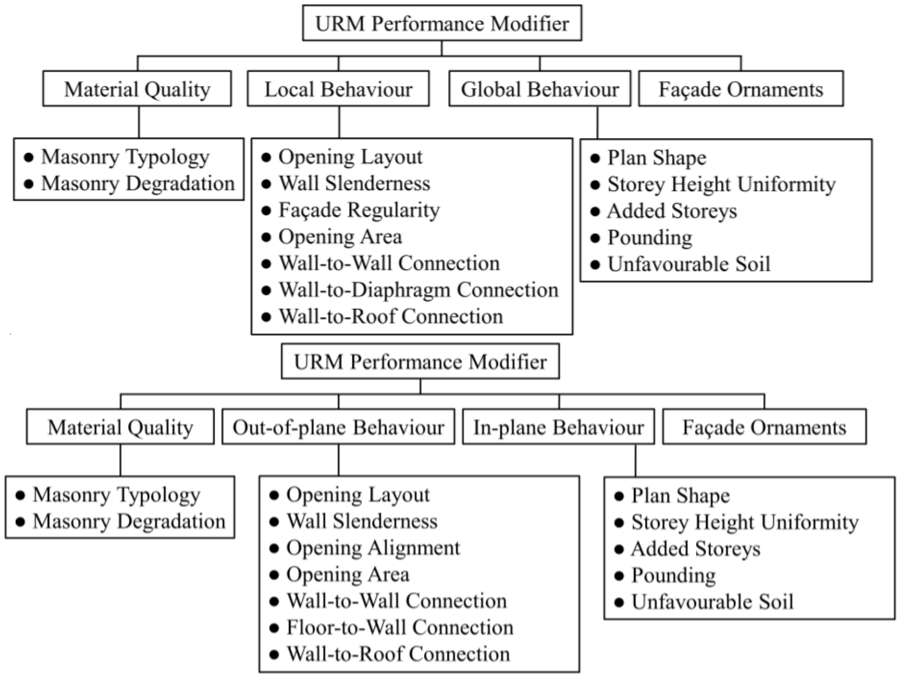


Figure 4: Performance modifier scheme.

The expert judgments expressing the relative importance of the considered RC-building secondary parameters (Table A.4) are calibrated accounting for the peculiarities of Filipino CH assets. In particular, infills at ground storey, presence of short columns and potential for pounding have been valued more important than the other secondary parameters. Indeed, many Filipino CH assets have non-engineered structures resulting from reconstructions and/or modifications over time. Therefore, these three vulnerability factors are commonly diffused. This choice results in a higher variability in the prioritisation~~prioritization~~ scheme. Table 4 provides guidance on the selection of the alternatives for the assignation of scores to the secondary parameters. One of the most important advantages of the proposed approach is the possibility to easily adapt it for the prioritisation~~prioritization~~ of other building typologies by simply considering various secondary parameters and modifying the expert judgments/weights ~~a~~ to reflect different construction features and their relative importance on the asset vulnerability. Only the consistency of the opinions must be checked through the calculation of ~~the~~ a consistency index (CI) as in Eq. 5, after the pairwise comparison:

$$CI = \frac{\lambda_{max} - r}{r - 1} \quad (5)$$

In Eq. 5, λ_{max} is the largest eigenvalue, calculated as solution of the AHP, while r is the rank of the judgment matrix. Finally, the CI is compared to a~~the~~ random consistency index (RCI), which is the average consistency index of a large number of randomly generated reciprocal matrices. If the CI is smaller than 10% of the RCI, the final values of the weights are logically sound and not a result of a random prioritisation. When such a criterion is not satisfied, the whole process should be repeated until an acceptable consistency is achieved (Saaty, 1980). The consistency condition is satisfied for all the comparisons used in the definition of the seismic index (Macro-categories: $CI = 0.0477 \leq 0.09 = 10\%RCI$; ~~Local~~ Out-of-plane behaviour: $CI = 0.0246 \leq 0.132 = 10\%RCI$; ~~Global~~ In-plane behaviour: $CI = 0.0615 \leq 0.112 = 10\%RCI$).

Table 3: Macro-categories and secondary parameters for URM buildings: definition, alternatives, scores and weights.

Macro-category	w_{MC}	Secondary Parameters	w_{SP}	Alternatives	Scores
Material Quality	0.4607	Material Typology	0.5	Chaotic stones	100
				Hollow brick / Regular sized stone	50
				Solid brick masonry and lime mortar / Concrete blocks	0
		Material Degradation	0.5	Significantly affecting performance (Poor structural condition)	100
				Moderately affecting performance (Good structural condition)	50
				Not affecting performance (Excellent structural condition)	0
~~Local~~ Out-of-plane Behaviour	0.2894	Opening Layout	0.0582	Opening with vert. alignment at both edges of the façade	100
				Opening with vert. alignment at only one edge of the façade	50
				Opening with vert. alignment at the centre of the façade	0
		Wall Slenderness	0.0346	High (h/l≥10)*	100
				Medium (5≤h/l≤10)	50
				Low (h/l≤5)	0
		~~Façade Regularity~~ Opening alignment	0.0975	Irregular (openings are not aligned)	100
				Medium (openings are vertically aligned)	50
				Regular (openings are horizontally and vertically aligned)	0
		Opening Area	0.0468	High (more than 50% of the total façade area)	100
				Medium (between 25% and 50% of the total façade area)	50
				Low (less 25% of the total façade area)	0
		Wall-to-Wall Connection	0.1923	Poor	100
				Adequate (mechanical connection)	0
		Floor-to-Wall ~~-to-Diaphragm~~ Connection	0.3696	Poor	100
				Adequate (ring beam)	0
		Wall-to-Roof Connection	0.2010	Poor	100
				Adequate (mechanical connection)	0
~~Global~~ In-plane Behaviour	0.1901	Plan Shape	0.1732	L-shape or irregular	100
				C-shape	50
				Rectangular or regular	0
		Storey Height Uniformity	0.1125	Significantly non-uniform (more than 0.5m difference)	100
				Moderately non-uniform (difference between 0 and 0.5 m)	50

				Uniform	0
		Added Storeys	0.1021	Yes	100
				No	0
		Pounding	0.4307	Pronounced (less than 0.1m gap)	100
				Moderate (gap between 0.1m and 0.2m)	50
				None (more than 0.2m gap)	0
		Unfavourable Soil	0.1815	Yes (very soft soil; liquefaction is not explicitly considered)	100
				No	0
Façade Ornaments	0.0598			Yes	100
				No	0

* h and l are the wall height and thickness respectively.

Table 4: Secondary parameters of RC buildings: definition, alternatives, scores and weights.

Secondary Parameters	w_{SP}	Alternatives	Scores
Preservation condition and/or existing damage	0.0939	Significantly affecting performance (Poor structural condition)	100
		Moderately affecting performance (Good structural condition)	50
		Not affecting performance (Excellent structural condition)	0
Plan Shape	0.0826	L-shape or irregular	100
		C-shape	50
		Rectangular or regular	0
Storey Height Uniformity	0.0470	Significantly non-uniform (more than 0.5m difference)	100
		Moderately non-uniform (difference between 0 and 0.5 m)	50
		Uniform	0
Added Storeys	0.0470	Yes	100
		No	0
Infills at ground storey	0.3039	Yes	100
		No	0
Short column	0.1817	Yes	100
		No	0
Pounding	0.1817	Pronounced (less than 0.1m gap)	100
		Moderate (gap between 0.1m and 0.2m)	50
		None (more than 0.2m gap)	0
Unfavourable Soil	0.0621	Yes (very soft soil; liquefaction is not explicitly considered)	100
		No	0

3.3 The wind prioritisation index

The proposed wind prioritisation~~prioritization~~ index for CH assets (I_W) is based on the vulnerability factors proposed by D'Ayala et al. (2020) ~~Nassirpour et al. (2018)~~ for the definition of the SCOSSO index, a multi-hazard vulnerability prioritisation~~prioritization~~ index for Filipino schools. The authors proposed a scoring method based on ratings related to specific building features which are combined to determine an overall damageability index. Particularly important for the aims of this study is the set of roof vulnerability factors related to the wind hazard. The authors considered eight construction features, also used in this study, which represent: the entire building construction features (*Code level* and *Number of Storeys*), the roof construction features (*Roof Structure*, *Roof Covering* and *Roof Pitch*) the *Roof Connection*, and the material conditions

(*Roof Condition* and *Structural Condition*). As for the case of the seismic prioritisationprioritization index, the code level follows the classification proposed by the HAZUS model (Kircher et al., 2006). Adopting the same code classification for the seismic and wind indices enables the proposed procedure to be consistent.

The proposed wind prioritisationprioritization index (I_W) is defined as a proxy for the relative wind risk of the considered buildings within the analysed portfolio. In fact, I_W (Eq. 6) is calculated as the weighted summation of scores ($SCORE_{wind}$) related to the structure of the roof and the presence of vulnerability factors (Table 5), which are then multiplied by a hazard parameter ($\widehat{w}_H$).

$$I_W = \widehat{w}_H \sum_{i=1}^{8} w_{VF,i} SCORE_{wind,i} \qquad (6)$$

The score values are in the range [0%, 100%] and they allow analysts to convert a qualitative judgment on the status of a particular vulnerability factor into a quantitative indicator. The hazard parameter reflects the wind hazard of the region where the analysed asset is located. Even though the wind hazard in the Philippines is fairly homogeneous, three regions are herein considered: west coastal areas (low wind hazard), central part of the country (medium wind hazard) and east coastal regions (high wind hazard). In fact, according to the National Structural Code of the Philippines (2015), the wind hazard increases from the east coast to the west coast of the country.

The combination weights ($w_{VF,i}$) are calibrated through the use of AHP to reflect their relative importance, according to the expert judgments reported in Table A.5. As discussed in the previous sections, the non-engineered nature of the Filipino CH asset roofs promotes pullout (of fasteners) and pullover – (of panels) failures (panel). Therefore, the *Roof Connection* is considered the most important parameter. Immediately after that, material conditions and *Construction years* play a fundamental role. Degraded materials can lead to the roof failure even if good quality connections are installed, while modern constructions should ensure a higher level of reliability than older ones (given good connections and materials). The remaining parameters can affect the roof system behaviour only if those previously listed are negligibledo not significantly affect the roof performance. The judgments assumed for the wind vulnerability factors in this application lead to $CI = 0.0297$ and $RCI = 1.41$, thus satisficing the consistency condition.

The AHP is also used to calibrate the values of the hazard parameters ($\widehat{w}_H$), reflecting the judgment matrix reported in Table A.6. Clearly, areas with high wind hazard are valued more important than medium and low wind hazard. The hazard parameters ($\widehat{w}_H$) are finally determined by normalising the AHP weights (w_H) as shown in Table 6. The consistency index and the random consistency index are $CI = 0.046$ and $RCI = 0.58$ respectively.

3.4 Combination of risk prioritisationprioritization indices

Once prioritisationprioritization indices related to different hazards are calculated, they must be properly combined in order to obtain a comprehensive indicator of the relative multi-hazard risk of the considered assets within the analysed portfolio.

In this study the multi-hazard risk prioritisationprioritization index (I_{multi}) is calculated as the Euclidian norm of the vectors whose components are the k single-hazard prioritisationprioritization indices (I_k) (Eq. 7).

$$I_{multi} = \sqrt{\sum_k I_k^2} \qquad (7)$$

Eq. 7 can be applied only if the single-hazard risk prioritisation~~prioritization~~ indices (I_k) have the same range of variation. However, the resulting multi-hazard risk prioritisation~~prioritization~~ index (I_{multi}) will be characterised by a different range. This can be rescaled in any other desired range without affecting the prioritisation list of the considered building portfolio. This simple combination rule does not introduce any further subjectivity into the framework, and it can be applied even when numerous hazards are considered. However, this method does not consider neither the interaction of different hazards at the various levels of the risk assessment chain nor weights for the different hazard prioritisation~~prioritization~~ indices.

Table 5: Wind vulnerability factors: definition, alternatives, scores and weights.

Vulnerability Factors	w_{VF}	Alternatives	Scores
Code level	0.1623	Pre-code	100
		Low code	66
		Moderate code	33
		High code	0
Number of storeys	0.0436	More than 3 storeys	100
		2:3 storeys	50
		1 storey	0
Structural condition	0.1725	Deteriorated / poor	100
		Fair / good	50
		New / excellent	0
Roof Structure	0.0838	Bricks	100
		Timber truss	66
		RC slab	33
		Steel truss	0
Roof Covering	0.0671	Tiles	100
		Iron sheets	50
Roof Pitch	0.0943	Multi-pitch	100
		Mono-pitch	50
		Flat	0
Roof Condition	0.1715	Deteriorated / poor	100
		Fair / good	50
		New / excellent	0
Roof Connection	0.2049	Deteriorated / poor	100
		Fair / good	50
		New / excellent	0

Table 6: Wind hazard parameters.

Wind hazard	w_H	$\hat{w}_H$	Description
High hazard	0.540	1	East coastal areas (basic wind speed with a 15% probability of exceedance in 50 years: between 290 kph and 320 kph).
Medium hazard	0.297	0.550	Central part of the country (basic wind speed with a 15% probability of exceedance in 50 years: between 270 kph and 290 kph).
Low hazard	0.163	0.302	West coastal areas (basic wind speed with a 15% probability of exceedance in 50 years: between 240 kph and 270 kph).

Loss curves (i.e., loss values versus their annual probability of exceedance) for various individual hazards, and calculated for a specific region, show different non-linear trends (Fleming et al., 2016). Therefore, considering different return periods, the relative effect of two catastrophic events (related to two different hazards) on the built environment may completely change. For instance, for low return periods, such as 100 years, earthquake and extreme-wind economic losses are comparable, while for high return periods, such as 1000 years, the economic loss related to seismic events is usually higher than that related to extreme-winds. This fact may be considered within the proposed framework by defining suitable combination weights for the single-hazard prioritisation~~prioritization~~ indices in Eq. 7. Such combination weights should vary with the mean return period of interest selected for the prioritisation~~prioritization~~ in order to express how every considered hazard contribute to the total loss. This would require a priori loss curves, which are usually not available for developing countries.

3.5 The value of CH assets

The proper definition of the asset exposure is a fundamental step of the risk assessment process, requiring the quantification of the asset value. As discussed in *Sections 1* and *2*, this task is particularly complex for CH assets because of their multiple impacts (e.g. economic, social, spiritual) which cannot be solely determined in monetary terms, similarly to other building typologies. Moreover, the relatively broad definition of cultural heritage adopted in different countries (no standardised definition exists; e.g., European Commission, 2018; Filipino Republic Act no. 10066, 2009) makes even more complex the quantification of the CH asset exposure. Most of the methods proposed in the scientific literature often neglect the CH asset exposure, thus considering vulnerability prioritisation~~prioritization~~ indices or assuming a homogeneous exposure for the whole building portfolio.

The simplified approach for considering the intangible value of CH assets in the prioritisation~~prioritization~~ scheme (lowest refinement level) proposed in this study assumes that the tangible values (direct and indirect costs) is constant for the entire portfolio, so that it does not affect the prioritisation~~prioritization~~ scheme. As discussed in *Section 1*, the intangible value is peculiar to each specific CH asset, and then it cannot be considered constant for the entire portfolio. Therefore, a score approach is proposed for its quantification through the calculation of the CH value index ($I_{CH\ value}$). It assumes the intangible value linked to the significance as "monument" of the CH asset by adopting the classification issued by Kerr (2013). Four categories are considered for the definition of the scores: *Word Heritage*, *National Heritage*, *National/Local Heritage* and *Local Heritage*. Table A.7. shows the expert judgments assigned to express the relative importance of each significance category and needed for the calculation of the scores through the AHP. The judgments express the idea that the intangible value increases with the significance of the analysed CH asset. Table 7 provides guidance for the selection of the appropriated CH significance and it reports the relative scores for which the consistency condition is satisfied ($CI = 0.01 \leq RCI = 0.9$).

It is worth noting that the classification of the CH asset significance proposed by Kerr (2013) has been already successfully used/validated in the scientific literature for the quantification of the intangible value (e.g., Romão and Paupério, 2020; Figueiredo et al., 2019). This further strengthens the validity of the proposed procedure.

Finally, after a ~~normalization~~ normalisation process of the CH value index ($I_{CH\ value}$), which allows for the calculation of $\hat{I}_{CH\ value}$, the multi-hazard risk prioritisation~~prioritization~~ index which considers the CH value ($I_{multi,CH\ value}$) can be calculated as

$$I_{multi,CH\ value} = I_{multi}\hat{I}_{CH\ value}. \tag{8}$$

Table 7: CH significance scores.

CH status	$I_{CH\ value}$	$\hat{I}_{CH\ value}$	Description
Exceptional significance	0.4673	1	The CH asset is considered a world heritage; it is characterised by an exceptional significance recognised worldwide.
Considerable significance	0.2772	0.5932	The CH asset is listed among the CH assets of national interest; it has national significance and it is possibly protected by national organisations.
Some significance	0.1601	0.3426	The CH asset has features of national significance but insufficient to be recognised as CH of national interest.
Little significance	0.0954	0.2042	The CH asset is characterised by local significance, so it has no national significance.

4 Case-study: CH assets in Iloilo City, Philippines

4.1 Description of Filipino CH assets

Recent catastrophic events, e.g., the M7.2 2013 Bohol earthquake or the 2013 Typhoon Haiyan, have highlighted how Filipino CH assets are particularly vulnerable to natural hazards due to ageing and type of construction. As already discussed, CH assets and communities are doubly tied because of their economic and social connections. This link is even more important in developing countries where ~~the~~ cultural tourism is seen as one of the priority sectors by which governments aim to foster inclusive and sustainable socio-economic development, due to its potential for job creation and revenues. For instance, according to the Philippines Statistics Authority (2019) the contribution of tourism to the Philippine economy was 12.7 % of GDP in 2018.

The proposed multi-hazard framework for risk prioritisation~~prioritization~~ of CH assets has been tested on 25 CH buildings located in Iloilo City, Philippines (Figure 5), one of the oldest cities and a touristic hub in the country, which contains a collection of historic sites, monuments, and CH buildings. ~~Realizing~~ Realising the importance of preserving its heritage, the city government has actively pursued the advocacy of promoting the city's culture, by identifying heritage zones and instituting a Heritage Conservation Council to oversee and promote CH preservation.

With three active faults in the near proximity of the city, Iloilo City is listed under Seismic Zone 4 in the official seismic map of the Philippines by the Philippine Institute of Volcanology and Seismology (National Structural Code of the Philippines, 2015). According to GEM (Pagani et al., 2018), the seismic hazard in Iloilo City, in terms of PGA with a 10% of probability of exceedance in 50 years, is in the range 0.35g to 0.55g. Since the city is also situated in Zone II of the Philippines Wind Zone Map (i.e., the three-second gust speed at 10m above the ground is equal to 117 km/h by assuming a return period of 50 years), it represents a perfect case study to assess the feasibility of the proposed approach.

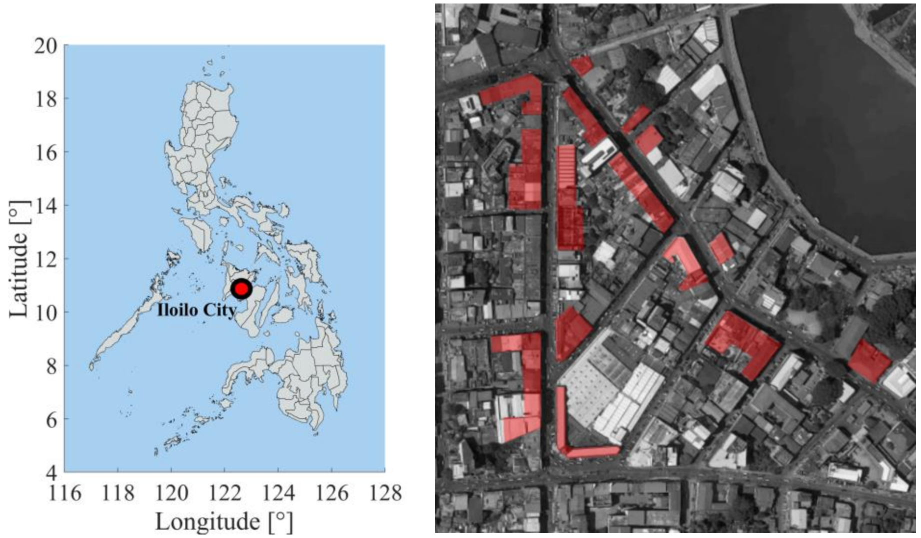


Figure 5: Surveyed CH buildings in Iloilo city, Philippines. Background imagery by ©2019 CNES / Airbus, Maxar Technologies, map data by ©2019 Google.

The analysed building portfolio is composed of URM and RC frame-type structures. Most of the building construction years are dated around the beginning of the last century; however, during their operational life, the Iloilo City CH assets experienced catastrophic events (e.g., earthquake and fire) which led to their partial or total reconstruction. As discussed above, new technologies have been used during the fieldwork in order to help the surveyors in the data collection exercise. In particular, drones have been extensively used for façade and roof inspections. As an example, Figure 6a shows the façade of the "Villanueva building" (ICCHCC, 2010), while Figure 6b shows the building roof. The "Villanueva building" is a L-shape, two-storey RC frame, whose roof was inaccessible; the drone was the only practicable tool for collecting roof data/information. The only limitation on the use of drones was the strong wind during the fieldwork, which strongly affected the flight capability. This important aspect must be considered when a survey campaign has to be ~~organized~~ organised in a cyclonic region. Figures 6c and Figure 6d respectively show the "Villanueva building 6" (ICCHCC, 2010) façade and its point cloud obtained by elaborating the pictures taken by smartphone and photo camera. Photogrammetry is a powerful tool for the construction of point clouds, but specific practical rules must be followed to obtain good quality results. This technology requires high quality pictures of the façades with ~~a~~ specific ~~overlapping~~overlaps, according to the software used during the elaboration step. A good quality point cloud can be obtained only if the façade is clear enough of obstacles, such as cars and people. This aspect must be considered during the planning phase of the survey campaign. Ideally, the pictures needed for photogrammetry should be taken during the hours in which there is less traffic, usually early morning.

a) b) c) d)

Figure 6: Use of new technologies for the survey of the Iloilo City CH assets: Villanueva building front façade (a), and roof (b) by drone; Villanueva building 6 frontal façade (c) and point cloud (d) by drone and photogrammetry respectively.

4.2 Main statistics of the data collected during the fieldwork

The main statistics derived from the data collected during the fieldwork are reported in Figure 7. Most of the surveyed CH assets are two-storey~~ (Figure 7a)~~, plan-regular buildings~~ (Figure7b)~~, somehow justifying their good performance during the M7.8 1948 Lady Caycay earthquake, the second largest event in the 500-year history of Philippine seismic activities (Geoscience Australia, 2012). The surveyed buildings are located within a complex urban context; in fact, they are parts of blocks with different shapes and compositions~~ (Figure 7c)~~, thus complicating the estimation of their seismic vulnerability. The statistics of the *Structural condition* ~~(Figure 7d) ~~highlight the level of degradation and the lack of maintenance for the assets under investigation. Specifically, 60% of the surveyed buildings show *Structural conditions* which moderately affect the building performances. This means presence of deficiencies which may moderately affect the structural performance, such as small cracks concentrated on a limited number of structural elements and infill panels, and/or limited damage of the roof. Whereas, 36% of the considered assets shows *Structural conditions* which may significantly affect the building performance, such as widespread cracks on structural elements, concrete cover crushing with rusty rebars and extended damage of the roof. Most of the structure deficiencies are due to a poor quality of the construction materials. The unusually large dimension of the aggregates together with an extreme heterogeneity in their distribution within the structural elements are the main causes of the bad performance of the materials.

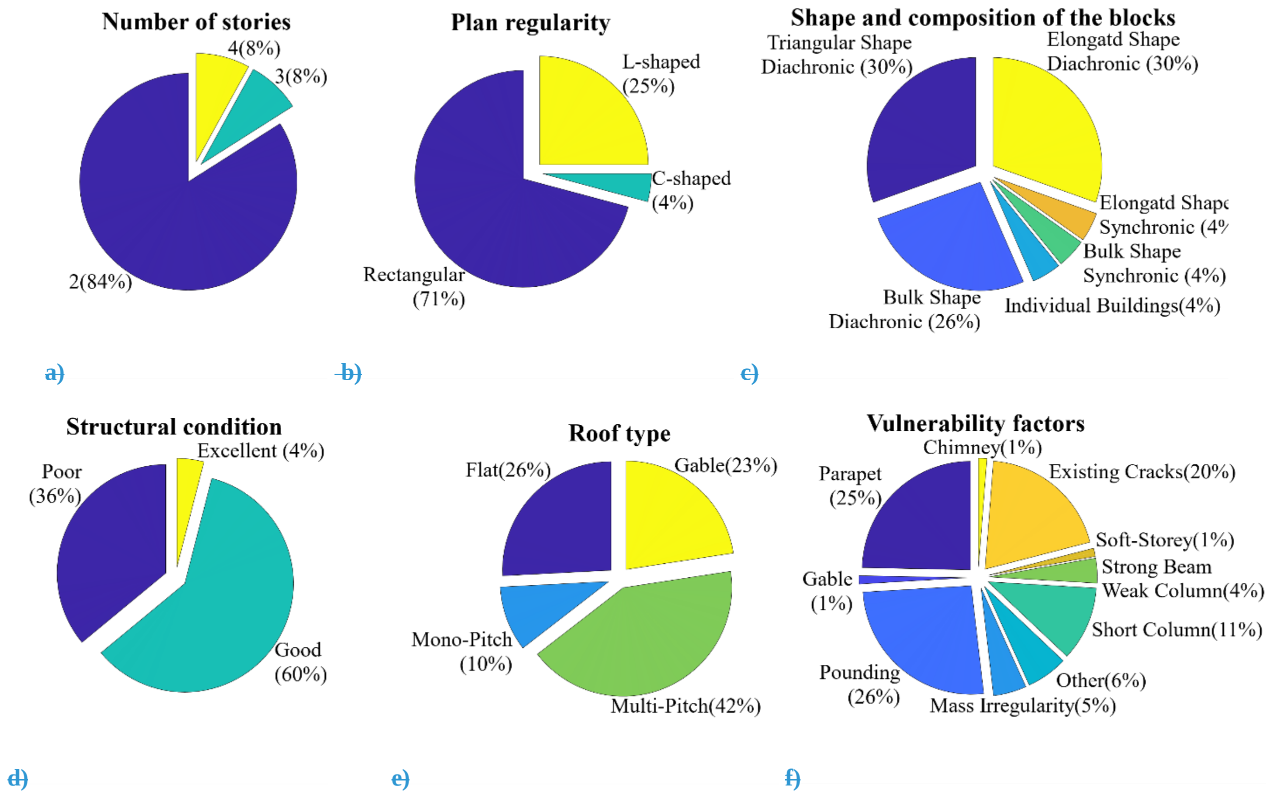


Figure 7: Statistics for the 25 surveyed CH buildings, Iloilo City, Philippines.

Figure 7f shows a widespread presence of various vulnerability factors. The most common and dangerous vulnerability is the potential for pounding and the presence of short columns. This can be explained by the use of obsolete codes during the design and construction of these assets. Moreover, regarding the potential for pounding, the high annual population growth rate in Iloilo City has led to construction in all the available space, without concern for the distance between buildings. According to Figure 7e, various typologies of roof made by different construction materials can be found. Flat roofs are mainly made by concrete, while gable, mono- and multi-pitch ones are generally characterised by a timber structure and metal roof sheets. An advanced degradation level affects the elements of the roofs, the structure and also the connections, i.e. fasteners and roof-to-wall connections, thus further increasing their vulnerability.

4.3 Prioritisation~~Prioritization~~ scheme

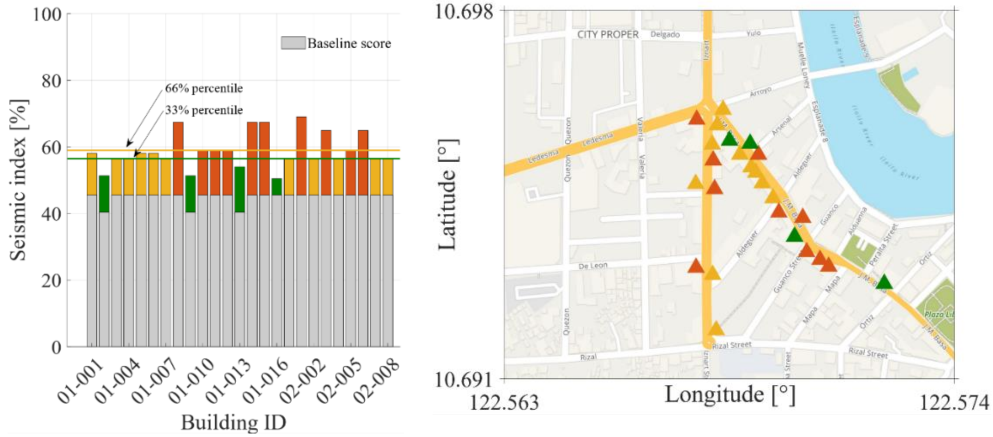
The collected data have been finally used for the calculation of the risk prioritisation~~prioritization~~ indices proposed in this study (*Section 3*). The resulting indices are arbitrarily ~~categorized~~ categorised in three groups, respectively "green, yellow and red tags" by defining two thresholds. The definition of such thresholds is essentially a subjective (often political) choice that shapes the prioritisation~~prioritization~~ scheme, based for instance on resources availability. For a governmental agency, those can be calibrated estimating the average structural retrofit (or relocation) cost per building and defining the amount of available public funding in two or more-time windows (e.g. one and five years) to obtain specified DRR objectives. As a proof of concept, in this paper the thresholds are selected to be equal to 33% and 66% for the calculated seismic, wind or multi-hazard indices.

The seismic risk prioritisation~~prioritization~~ indices (Figure 8a) show fairly homogeneous baseline scores, indicated with grey bars. This is due to the common construction features of the analysed CH assets. In fact, most of them are regular RC frame structures built before the 1970, and so they are considered pre-code structures. Figure 8a also highlights how important the performance modifiers, and so the vulnerability factors, are in the definition of the seismic prioritisation~~prioritization~~ scheme. The analysed CH assets have common vulnerability factors, in particular *Pounding*, and diffused degradation. These increase the values of the seismic risk prioritisation~~prioritization~~ indices, in fact only four assets are below the 33th percentile. This also leads to a relatively small variability of the results. Due to relatively small extension of the survey area, the same *Unfavourable Soil* condition are assumed for all CH assets (Table 3).

The wind risk prioritisation~~prioritization~~ indices (Figure 8b) show a higher variability if compared with the seismic ones. This is mainly due to the different construction features and degradation conditions of CH asset roofs observed during the survey. Highly degraded roofs are strongly penalised by the scores considered in this study (Table 5). Therefore, structures with the worst maintenance conditions show the highest values of the wind risk prioritisation~~prioritization~~ indices. In this study, all of the CH assets are considered located in the same hazard region (medium hazard Table 6).

The two indices are finally combined following the procedure proposed in *Section 3.4* thus obtaining the multi-hazard prioritisation~~prioritization~~ indices (I_{multi}) shown in Figure 8c. The results clearly indicate that the wind hazard plays a substantial role in determining the prioritisation scheme for the CH assets in Iloilo city. Indeed, the overall trend of the multi-hazard results is practically the same of the wind indices.

Finally, the intangible value of CH assets is considered in the definition of the prioritisation~~prioritization~~ scheme according to the procedure proposed in *Section 3.5*. In order to assess the validity of the proposed procedure the analysed CH assets are assumed to be characterised by local significance, except for the building 01-013, one of the assets which behave better, whose significance is considered recognised at national level. Figure 9 shows the multi-hazard prioritisation~~prioritization~~ indices which consider the CH intangible value. The general trend is the same of the wind prioritisation~~prioritization~~ index, but the relative position of building 01-013 changes. This simple example shows that if the intangible value of CH assets within a given portfolio is not homogeneous it can drive the prioritisation~~prioritization~~ scheme.



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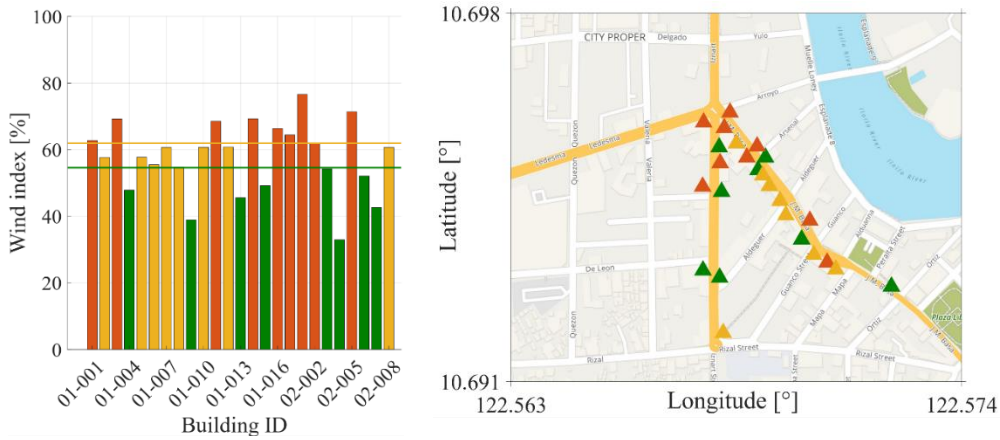

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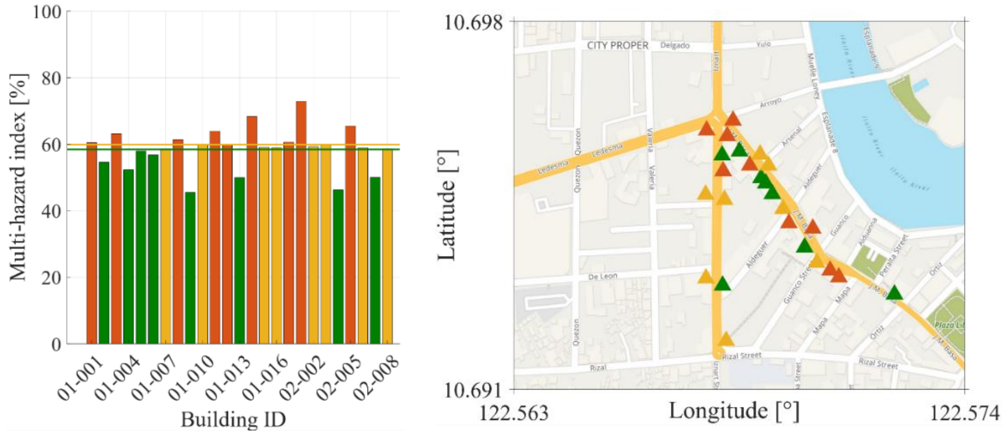

c)

Figure 8: Prioritisation~~Prioritization~~ indices: a) Seismic risk prioritisation~~prioritization~~ index; b) Wind risk prioritisation~~prioritization~~ index; c) Multi-hazard risk prioritisation~~prioritization~~ index. Background map by ©OpenStreetMap contributors 2019. Distributed under a Creative Commons BY-SA ~~License~~Licence.

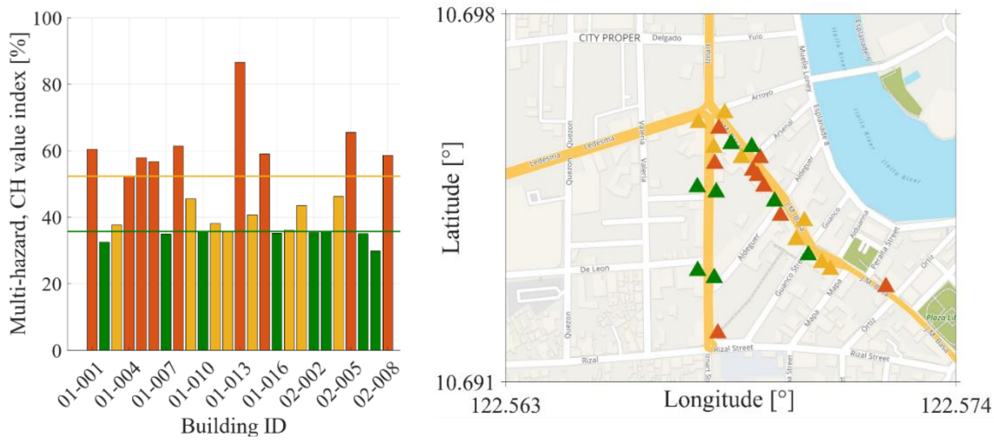

Figure 9: Multi-hazard risk prioritisation~~prioritization~~ index which considers the CH intangible value. Background map by ©OpenStreetMap contributors 2019. Distributed under a Creative Commons BY-SA ~~License~~Licence.

5 Concluding remarks

This paper presented a multi-hazard risk prioritisation~~prioritization~~ framework for CH assets which represents the lowest refinement level of a multi-level risk and resilience assessment procedure. This procedure is indeed one of the first outcomes of the *Cultural Heritage Resilience & Sustainability to multiple Hazards* (CHeRiSH) project, which aims to develop a multi-level, ~~harmonized~~harmonised, and engineering-based risk and resilience assessment framework for CH assets in the Philippines exposed to multiple natural hazards.

To this aim, an ad-hoc RVS form designed for CH assets has been introduced in this paper. In particular, the multi-level architecture of the proposed RVS form allows one to improve the estimation of the structural fragility and risk once new detailed information is available. At the lowest refinement level (the main focus of the paper), the data gathered in the RVS form are used for the calculation of the proposed seismic and wind prioritisation~~prioritization~~ indices. They represent empirical proxies for the relative risk of CH assets within the analysed portfolio and then they can be used only for prioritisation~~prioritization~~ purposes.

The proposed seismic risk prioritisation~~prioritization~~ index extended the one developed within the INSPIRE project to the case of URM buildings. It consists of two parts: a baseline score and a performance modifier. The baseline score calculation is based on the HAZUS model fragility curves, while the performance modifier is computed as weighted summation of scores related to macro-categories and secondary parameters, which, if present, are deemed to jeopardise the building performance. The macro-categories express the seismic failure chain peculiar of URM buildings. Each of them contributes to the calculation of the performance modifier through secondary parameters which express specific structural features which can prevent or promote the activation of failure mechanisms, as observed during post-earthquake surveys. The proposed wind risk prioritisation~~prioritization~~ index was similarly defined as the weighted summation of scores and weights related to vulnerability factors of CH asset roofs multiplied by a hazard parameter. The vulnerability factors defined within the SCOSSO project have been adapted in this work to the needs of CH assets. A simple method to combine risk prioritisation~~prioritization~~ indices related to different hazards and which allows considering the intangible value of CH assets has been finally introduced. The multi-hazard risk prioritisation~~prioritization~~ index was calculated as the Euclidian norm of the vector whose components are the single-hazard prioritisation~~prioritization~~ indices. The intangible CH asset value was considered by multiplying the multi-hazard risk prioritisation~~prioritization~~ index by a score that account for the significance of the asset as CH. The Analytic Hierarchy Process (AHP) has been extensively used to calibrate combination weights and scores, thus reducing the subjectivity involved in the procedure.

The application of the proposed prioritisation~~prioritization~~ framework on the CH assets of Iloilo City, Philippines, has shown its feasibility in practice. Findings from the fieldwork highlight the important role played by the widespread vulnerability factors, strongly affecting the performance of the surveyed CH assets. The case study highlighted the need of considering the intangible value of CH assets within prioritisation~~prioritization~~ procedures.

This study represents a first step toward a comprehensive framework for multi-hazard risk assessment and optimal resilience-enhancing strategy selection for CH assets. Future developments will aim to improve the quantification of the wind vulnerability through the definition of suitable numerical models which consider degradation effects and climate change impact.

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Appendix 1

Table A.1: Judgment matrix adopted for the calibration of the macro-category weights.

	Material quality	Local behaviour	Global behaviour	Façade ornaments
Material quality	1	2	3	5
Local behaviour	1/2	1	2	5
Global behaviour	1/3	1/2	1	5
Façade ornaments	1/5	1/5	1/5	1

Table A.2: Judgment matrix adopted for the calibration of the ~~local~~ out-of-plane behaviour weights.

	Opening Layout	Wall Slenderness	~~Façade Regularity~~Opening alignment	Opening Area	Wall-to-Wall Connection	Floor-to-Wall~~-to-Diaphragm~~ Connection	Wall-to-Roof Connection
Opening Layout	1	2	1/2	1	1/3	1/6	1/3
Wall Slenderness	1/2	1	1/2	1/2	1/6	1/8	1/6
Opening alignment~~Façade Regularity~~	2	2	1	2	1/2	1/3	1/2
Opening Area	1	2	1/2	1	1/6	1/8	1/6
Wall-to-Wall Connection	3	6	2	6	1	1/3	1
Floor-to-Wall Connection~~Wall-to-Diaphragm Connection~~	6	8	3	8	3	1	2
Wall-to-Roof Connection	3	6	2	6	1	1/2	1

Table A.3: Judgment matrix adopted for the calibration of the ~~global~~ in-plane behaviour weights.

	Plan shape	Storey height uniformity	Added storeys	Pounding	Unfavourable soil
Plan shape	1	2	2	1/2	1/2
Storey height uniformity	1/2	1	1	1/4	1
Added storeys	1/2	1	1	1/3	1/2
Pounding	2	4	3	1	4
Unfavourable soil	2	1	2	1/4	1

Table A.4: Judgment matrix adopted for the calibration of the RC building weights.

	Preservation condition	Plan Shape	Storey Height Uniformity	Added Storeys	Infills at ground storey	Short column	Pounding	Unfavourable Soil
Preservation condition	1	1	2	2	1/3	1/2	1/2	2
Plan shape	1	1	2	2	1/3	1/2	1/2	1/2

Storey height uniformity	1/2	1/2	1	1	1/6	1/4	1/4	1
Added storeys	1/2	1/2	1	1	1/6	1/4	1/4	1
Infills at ground storey	3	3	6	6	1	2	2	6
Short column	2	2	4	4	1/2	1	1	4
Pounding	2	2	4	4	1/2	1	1	4
Unfavourable soil	1/2	2	1	1	1/6	1/4	1/4	1

Table A.5: Judgment matrix adopted for the calibration of the roof vulnerability factor weights.

	Code level	Number of storeys	Roof Structure	Roof Covering	Roof Pitch	Roof Condition	Roof Connection	Structural Condition
Code level	1	3	2	2	2	1	1	1
Number of storeys	1/3	1	1/2	1/2	1/2	1/4	1/4	1/4
Roof structure	1/2	2	1	1	1	1/2	1/2	1/2
Roof covering	1/2	2	1	1	1	1/4	1/4	1/4
Roof pitch	1/2	2	1	1	1	1/2	1/2	1
Roof condition	1	4	2	4	2	1	1/2	1
Roof connection	1	4	2	4	2	2	1	1
Structural condition	1	4	2	4	1	1	1	1

Table A.6: Judgment matrix adopted for the calibration of the hazard parameters.

	High wind hazard	Medium wind hazard	Low wind hazard
High wind hazard	1	2	3
Medium wind hazard	1/2	1	2
Low wind hazard	1/3	1/2	1

Table A.7: Judgment matrix adopted for the calibration of the CH value scores.

	Exceptional significance	Considerable significance	Some significance	Little significance
Exceptional significance	1	2	3	4
Considerable significance	1/2	1	2	3
Some significance	1/3	1/2	1	2
Little significance	1/4	1/3	1/2	1