The CHeRiSH project: towards a multilevel, multi-hazard risk assessment framework for cultural heritage assets in the Philippines

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ABSTRACT

Multi-hazard risk assessment of building portfolios is of primary importance in natural hazard-prone areas, particularly for the definition of prioritization schemes for implementing Disaster Risk Reduction (DRR) and resilience-enhancing strategies. Among the most vulnerable buildings, cultural heritage (CH) assets are especially important because of their historical/cultural value, the lack of any hazard-resistant design (in most of the cases), and their material degradation due to aging. In this context, the *Cultural Heritage Resilience & Sustainability to multiple Hazards* (CHeRiSH) project, funded by the UK British Council, aims to develop a multi-level risk and resilience assessment framework for CH assets in the Philippines exposed to multiple natural hazards.

In this paper, an ad-hoc Rapid Visual Survey (RVS) form for the multi-hazard data collection and risk prioritization of CH assets, developed within CHeRiSH, is presented. 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 case-study assets.

The proposed framework has been 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. The data have been organized in a Building Information Modeling (BIM) platform specifically developed for the Filipino CH assets. The preliminary 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 is of paramount importance to define prioritization schemes for the optimization of resilience-enhancing strategies in natural hazard-prone areas. This is even more important in developing countries, where most of the existing building stock has been designed/built according to obsolete codes (if any) and limited financial resources are available for designing/implementing Disaster Risk Reduction (DRR) and resilience-enhancing strategies. Among the most vulnerable buildings, cultural heritage (CH) assets are especially important because of their high historical/cultural value, the lack of any hazard-resistant design (in most of the cases), and their material degradation due to aging. In fact, most of CH assets are characterized by nonengineered structures, usually built based on empirical knowledge and reflecting the tradition of a community (e.g., Ortega et al. 2019). Moreover, modifications over time, local repairs or partial/total reconstructions, which are widespread on CH assets, can even worsen their structural performance.

CH assets and communities are doubly tied because of their economic and social connections. On one hand, CH is directly linked to the economy of a region through cultural tourism. Indeed, besides the CH value itself, which is often difficult to quantify due to the uniqueness of a given asset, a large part of the tourist trade is linked to CH. Just as an example, according to Bartoloni and di Pillo (2017), the regions in Central Italy which experienced the 2016-2017 seismic sequence generated €9 billion of gross domestic product (GDP) in tourist trade, part of which was directly linked to CH. In the immediate aftermath of the earthquake, tourist arrivals declined drastically. On the other hand, CH has a symbolic value for a given community. The citizens' sense of place is strongly linked to CH assets: their damage and partial/total collapse can have a huge impact on social cohesion, sustainable development and psychological well-being. These issues, together with the difficulties in assigning a value on the non-market nature of many CH assets, make the quantification of their exposure to natural hazards a challenging task (e.g., European Commission, 2018).

A recent report prepared for the World Heritage Committee [1] 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*'. There is thus an urgent need to raise awareness about the need to integrate CH concerns into DRR plans. To this aim, simplified and rapid methods for multi-hazard risk assessment of building portfolios (e.g., FEMA P-154, 2015) represent essential tools to prioritize further detailed analyses and any DRR and/or resilience-enhancing intervention. Simplified methods for building portfolios often allow calculating risk prioritization indices against a specific (or multiple) hazard(s) by requiring only a limited amount of information about the structure under investigation. These approaches often rely on the definition of pre-determined building classes (e.g., Giuliani et al., 2019; Lagomarsino and Giovinazzi, 2006) and related fragility/vulnerability relationships for each class or Rapid Visual Survey (RVS) forms and empirically calibrated vulnerability/risk indices based on the RVS results (e.g., Ferreira et al., 2017; Uva et al., 2016).

In this context, the *Cultural Heritage Resilience & Sustainability to multiple Hazards* (CHeRiSH) project, funded by the UK British Council, aims to develop a multi-level risk and resilience assessment framework for CH assets in the Philippines exposed to multiple natural hazards.

Recent catastrophic events, e.g., the M7.2 2013 Bohol earthquake or the 2013 Typhoon Haiyan, have highlighted that Filipino CH assets are particularly vulnerable to natural hazards due to ageing and type of construction. According to the Philippines Statistics Authority (2019) the contribution of tourism to the Philippine economy was 12.7 % of GDP in 2018. Moreover, cultural tourism is one of the priority sectors by which the Government of the Philippines aims to foster inclusive and sustainable socio-economic development, due to its potential for job creation and revenues.

The CHeRiSH project has different objectives, involving civil and structural engineering as well as social science, arts and humanities. From the engineering perspective, the project aims to investigate 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. Ultimately, the project will provide conceptual guidelines for the development and implementation of each component of the proposed modelling framework. The main focus of the project is on the exposure and physical vulnerability modelling of CH assets as well as on the prioritization of resilience-improving solutions for selected assets through multi-criteria decision making. Whereas, 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 and local communities. Figure 1 schematically describes the main components of the CHeRiSH project and the interactions among various expertise of different partners, from both UK and Philippines side.

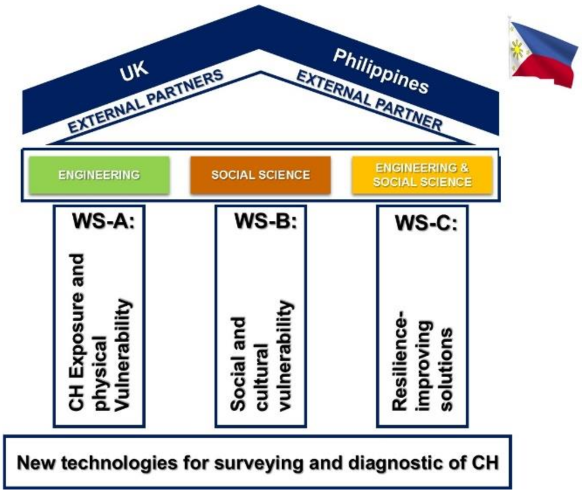

Figure 1. The CHeRiSH project: schematic representation.

Findings, protocols, and policy recommendations from CHeRiSH will support national and local governments and communities in both pre-and post-disaster plans for building resilience of CH assets to natural hazards.

As a first step towards CHeRiSH's overall aim, an *ad-hoc* RVS form for the multi-hazard risk prioritization of CH assets has been developed and presented in *Section 2* of this paper. Special

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[1] https://whc.unesco.org/en/disaster-risk-reduction/

emphasis is placed on the description of the RVS form, which is characterized by a multi-level architecture with the potential to improve the estimation of structural fragility and risk once new specific information about the building and site is available. The proposed RVS form is compatible with existing risk prioritization indices and can rely on the use of new technologies for CH assets survey and diagnostic, as discussed in the paper.

The proposed RVS form has been used for the multi-hazard risk prioritization of 25 CH assets in Iloilo City, Philippines, for which the main results are presented and discussed in *Section 3*. With a population of 447,992 inhabitants and a 1.02% population annual growth rate, Iloilo City is one of the most highly urbanized city 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 (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.

2 RISK PRIORITIZATION FRAMEWORK FOR CULTURAL HERITAGE ASSETS

2.1 Filipino CH assets and the proposed RVS form

RVS forms, specifically tailored for CH assets, and the related vulnerability/risk prioritization indices, have been widely used all around the world (e.g., Baggio et al. 2007; Jiménez et al. 2018; Ortega et al. 2019, among others). Due to the uniqueness and regional construction features of CH assets, RVS forms are hardly generalizable. Therefore, modifications and specifications, based on the characteristics of the CH assets in a particular region, are always needed to adapt a given RVS form in practice.

The Filipino CH assets mainly consist of reinforced concrete (RC) frames and masonry or mixed structures. Sometimes, more than one construction material and lateral-load resisting system can be found in the same asset as result of reconstructions or various modifications over the years. 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 the United Nations Educational, Scientific and Cultural Organization (UNESCO) (WHC 17/01, 2017) for the definition of CH assets, the Filipino law does not explicitly consider subjective features of the buildings such as the architectonical value and socio-cultural factors. Therefore, fairly recent RC frame-type structures characterized 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.

RVS forms are usually developed to collect data strictly needed for the calculation of vulnerability/risk prioritization indices for single or multiple hazards. However, the potential for improving the estimation of structural fragility and risk when new information is available is an essential feature for the implementation of DRR strategy for important assets (e.g., CH assets, critical infrastructure) at large scale, because various stakeholders may have different perspectives on this matter. For instance, government agencies are usually interested in large-scale prioritization methods for optimizing resource allocation for DRR intervention (e.g., structural retrofitting). However, private owners of single buildings or small portfolios of buildings likely require more refined analysis types and a higher degree of accuracy in the estimation of the risk profile of the asset.

The proposed RVS form (Figure 2) is therefore defined in a multi-level framework (e.g., Moratti et al., 2019), which allows one collecting information characterized by an increasing degree of accuracy. In this way, more detailed analyses can be performed when specific data is available.

The information required for the first level of refinement/accuracy (white entries in the RVS form) typically allows an analyst to define/compute risk prioritization indices. This data 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, coupled with a desk review to characterize the hazard profile at the given asset site.

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. Combining the information from the first two levels of refinement allows an analyst to perform a simplified structural analysis (e.g., D'Ayala and Speranza 2003; Gentile et al., 2019), thus improving the estimation of the building performance.

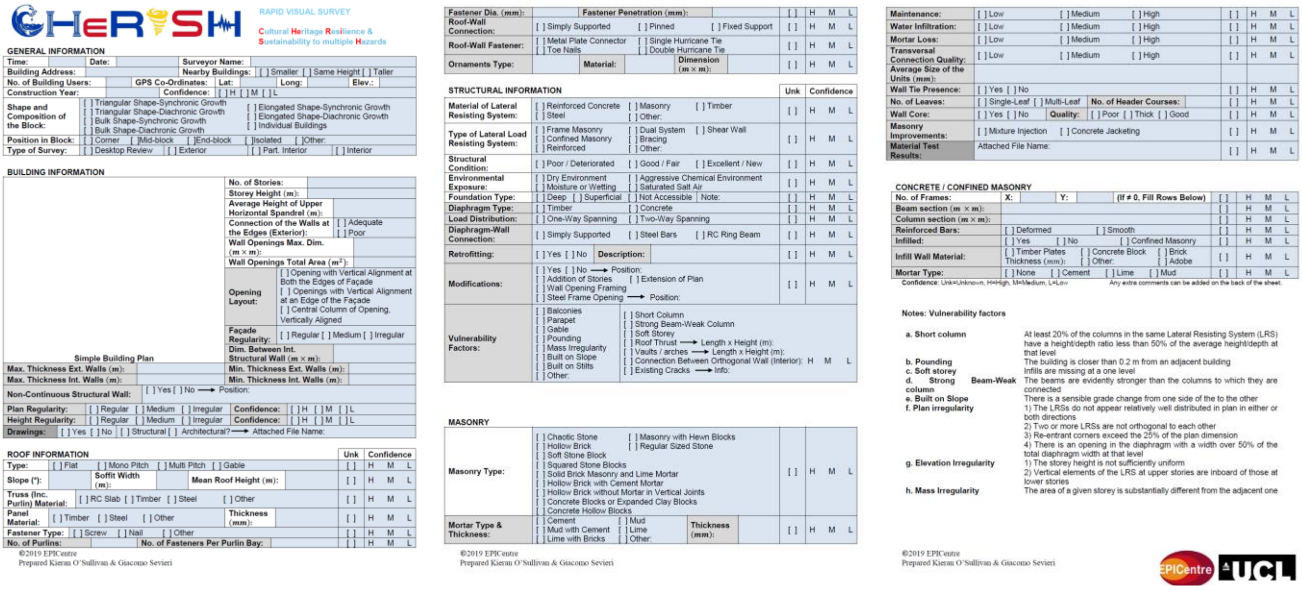
The third level of refinement/accuracy (dark grey entries) allows an analyst to perform a highly-detailed structural analysis of the building, thus further improving the structural fragility estimation, ideally deriving building-specific fragility/vulnerability relationships. Material test results and structural drawings should also be available at this stage 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 each parameter, thus accounting for the degree of uncertainty in the collected data in the calculation of the prioritization index.

Special emphasis has been placed on the design of "Vulnerability Factors" and the "Roof Information" sections. More specifically, the "Vulnerability Factors" section contains a list of vulnerabilities which can be found in the survey of masonry or RC structures. They have been selected after an extensive literature review (e.g., Baggio et al. 2007; D'Ayala 2013) and by keeping in mind the particular features of the Filipino CH assets (Yu and Oreta 2014). The 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 (e.g., 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.

2.2 Compatibility with existing risk prioritization indices

One of the main aims of the proposed RVS form is the calculation of multi-hazard risk prioritization indices for CH assets. 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 Hazard United States (HAZUS) model (Kircher et al. 2006).



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

Simple Building Plan		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 $(m \times m)$:	
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

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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 [ ] Toe Nails	[ ] Single Hurricane Tie [ ] 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 [ ] Steel	[ ] Masonry [ ] Other:	[ ] Timber	[ ]	H M L
Type of Lateral Load Resisting System:	[ ] Frame Masonry [ ] Confined Masonry [ ] Reinforced	[ ] Dual System [ ] Bracing [ ] Other:	[ ] Shear Wall	[ ]	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
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 [ ] Hollow Brick [ ] 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	[ ] Masonry with Hewn Blocks [ ] Regular Sized Stone			[ ]	H M L
Mortar Type & Thickness:	[ ] Cement [ ] Mud with Cement [ ] Lime with Bricks	[ ] Mud [ ] Lime [ ] Other:	Thickness (mm):		[ ]	H M L

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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 Thickness (mm):	[ ] Concrete Block [ ] Other:	[ ] Brick [ ] 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

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Figure 2. The CHeRiSH RVS form.

In this way, existing prioritization indices based on these two models can be used within the proposed framework.

In this study, the INSPIRE (*INdonesia School Programme to Increase REsilience*) index proposed by Gentile et al. (2019) is used to evaluate the seismic performance of the Filipino CH assets for prioritization purposes. With the same aim, the procedure proposed by Nassirpour et al. (2018), within the SCOSSO (Safer COmmunities through Safer SchOols) project, is used for the calculation of a wind risk prioritization index.

Specifically, the INSPIRE index is a seismic risk prioritization index developed for RC (school) buildings. It requires the calculation of a baseline score and of a performance modifier, which are then combined in order to calculate the final prioritization index. The baseline score is based on the fragility curves available in HAZUS. These fragility curves represent the seismic performance of archetype buildings which are classified based on four basic parameters: material, basic structural system, building height and seismic code level. Once a particular Damage State (DS) of interest is selected, the probability of exceeding it is calculated for three levels of Peak Ground Acceleration (PGA) - corresponding to low, moderate and high seismicity levels - and for each considered archetype building category. The analyst will select the seismicity levels appropriate for the considered building portfolio and with regard to the analyzed geographic area. In this way, it is possible to map the building basic parameters to the exceeding probability of the DS of interest conditional to the considered PGA value. The baseline score is defined in order to be proportional to such exceeding probability after a rescaling in the range 1%-50% based on the maximum and minimum DS exceeding probability in the complete HAZUS database; see Gentile et al. (2019) for details. The performance modifier represents the perturbation of the baseline score due to the presence of vulnerability factors. It is calculated as a weighted average of the scores assigned to eight secondary parameters: preservation condition, plane shape, story height uniformity, added stories, infills at ground story, short column, pounding and unfavorable soil. Their weights, calibrated through the Analytical Hierarchy Process (Saaty, 1980) to minimize subjectivity, allow the analyst to consider the relative importance of these vulnerability factors on the overall risk index for a given asset.

Similarly to the INSPIRE index, the calculation of the wind risk prioritization index according to the SCOSSO procedure requires transforming qualitative judgments into quantitative scores, which are then used to calculate the final index as a weighted average of the scores assigned to various parameters. The focus here is on the roofs and their particular characteristics, e.g. roof condition, roof connection and roof pitch; see Nassirpour et al. (2018) for details.

2.3 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 are used both for private and public activities. This complicates and slows down survey campaigns because it limits the possibility to access the various areas of the construction and to properly collect data. Moreover, the application of invasive tests on CH assets is not feasible because of the value and the uniqueness of the surveyed constructions. Hence, new technologies can help surveyors during the data collection to overcome those challenges and speeding up the fieldwork.

In fact, one of the objectives of the CHeRiSH project is to test the feasibility of applying new technologies for the survey of CH assets. In particular, during the fieldwork, omnidirectional cameras, thermal cameras, drones, photogrammetry, and Building Information Modeling (BIM) have been extensively used.

Omnidirectional cameras allow taking 360° pictures which 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. Therefore, having the opportunity to review 360° pictures is particularly helpful in this context.

Similarly, the collection of reliable measurements of the building exterior is a challenging task, especially in densely populated cities, as the case study considered here. Indeed, car traffic, people and temporary obstacles prevent the architectural survey. Therefore, as in the case of interior measurements, exterior point clouds can be analyzed 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. Arguably, the elaboration of the pictures requires specific software and expertise.

The quality and typology of the masonry characterizing a given asset, and the diaphragm characteristics (e.g., its orientation) are essential information needed even at the first level of refinement 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 (e.g., Mercuri et al. 2015). Thermal cameras allow one detecting 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 by different thermal properties (e.g., emissivity coefficients), their presence within the structure can be easily detected just taking a picture. However, the use of thermal cameras is strictly linked 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 detected.

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 use of drones (e.g., Themistocleous 2018) is then particularly useful to carry out a reliable roof inspection and build accurate numerical models for wind fragility estimation (e.g., Song et al. 2019).

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 Building Information Modeling (BIM) (e.g., Logothetis et al. 2015) 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 of 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 THE CULTURAL HERITAGE ASSETS OF ILILO CITY

The proposed CHeRiSH RVS form has been tested on 25 CH buildings located in Iloilo City, Philippines, one of the oldest cities and a touristic hub in the country, which contains a collection of historic sites, monuments, and CH buildings. Realizing the importance of preserving these CH assets, 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, ranges from 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), Iloilo City represents a perfect case study to assess the feasibility of the proposed approach.

Among the 25 surveyed CH buildings only one is a masonry construction, while the other 24 are RC frame-type structures. In fact, 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.

New technologies have been used during the fieldwork in order to help the surveyors in the data collection exercise, as described in *Section 2*. For instance, drones have been extensively used for façade and roof inspections. As an example, Figure 3a shows the façade of the “Villanueva building” (ID 01-008) (ICCHCC 2010), while Figure 3b shows the building roof. The “Villanueva building” is a L-shape, two-story 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 in a cyclonic region. Figures 3c and Figure 3d respectively show the “Villanueva building 6” (ID 01-018) (ICCHCC 2010) façade and its point cloud obtained by elaborating the pictures taken by smartphone and photo camera. As discussed in *Section 2*, photogrammetry is a powerful tool for the construction of point clouds, even if some specific rules must be followed in order to obtain a reliable result. Indeed, this technology requires high quality pictures of the façades with a specific overlapping, according to the software used during the elaboration step. Moreover, 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.

The main statistics derived from the data collected during the fieldwork are reported in Figure 4. The surveyed buildings are located within a complex urban context; in fact, they are parts of blocks with different shapes and compositions, thus complicating the estimation of their seismic vulnerability. However, most of them are two-story, plan-regular buildings, somehow justifying the good performance of these buildings during the M7.8 1948 Lady Caycay earthquake, the second largest event in the 500-year history of Philippine seismic activities (Geoscience Australia 2012).

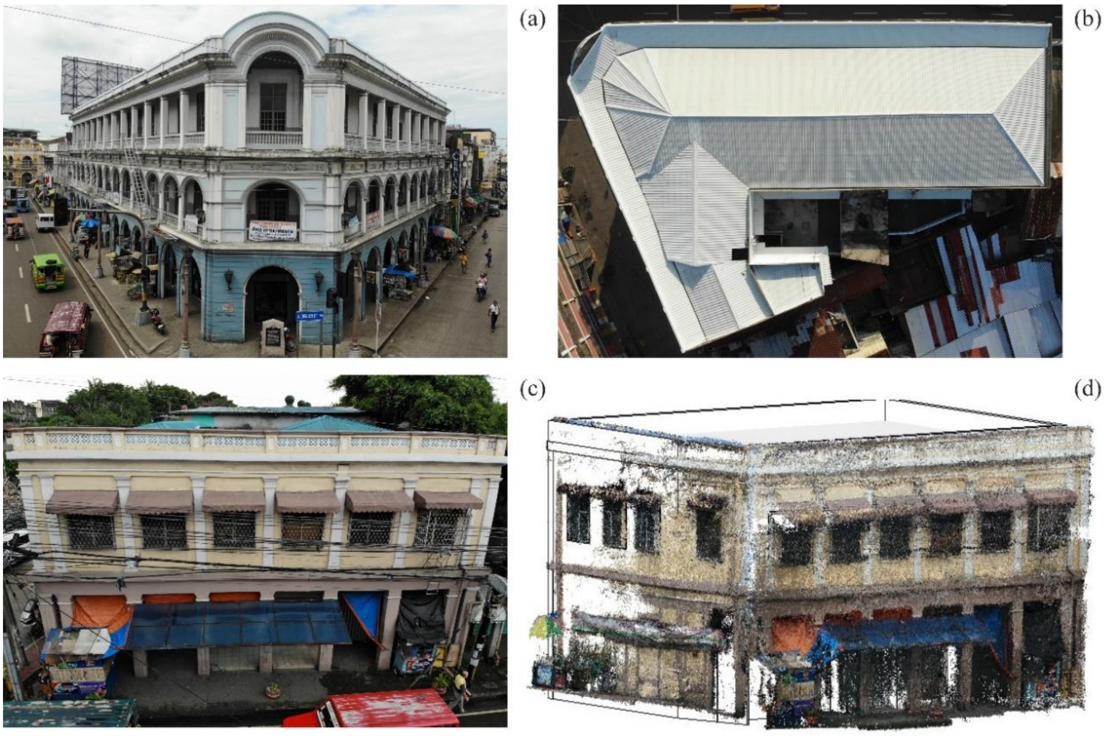

Figure 3. Use of new technologies for the survey of the Iloilo City CH assets: Villanueva building (ID 01-008) front façade (a), and roof (b) by drone; Villanueva building 6 (ID 01-018) frontal façade (c) and point cloud (d) by drone and photogrammetry respectively.

The statistics of the “Structural condition” highlight the level of degradation and the lack of maintenance for the assets under investigation. Specifically, 60% of the surveyed buildings show a “good” stuctural condition. This means presence of deficiencies which may modaratley affect the structural performance, such as small cracks concentrated on a limited number of structural elements and infill panels, and/or limited damge of the roof. Whereas, 36% of the considered assets shows “poor” structural conditions which may significanlty affect the building performance, such as widespread cracks on structural elements, concrete cover crushing with rusty rebars and extended damage of the roof. An illustrative example is shown in Figure 5 where two columns present deep vertical cracks (Figure 5, left), and concrete cover crushing (Figure 5, right). 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 4 also 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 4, 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 caracterised 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. fastners and roof-to-wall connections, thus further increasing their vulnerability

The collected data have been finally used for the calculation of the risk prioritization indices by using the INSPIRE and the SCOSSO approaches described in *Section 2.2*. As previously explained, the calculation of the baseline score of the INSPIRE index requires the knowledge of the seismic code level. Due to the reported year of construction for most of the considered assets (i.e., approximately the first half of the 20th century) pre-code fragility curves were selected for all the buildings.

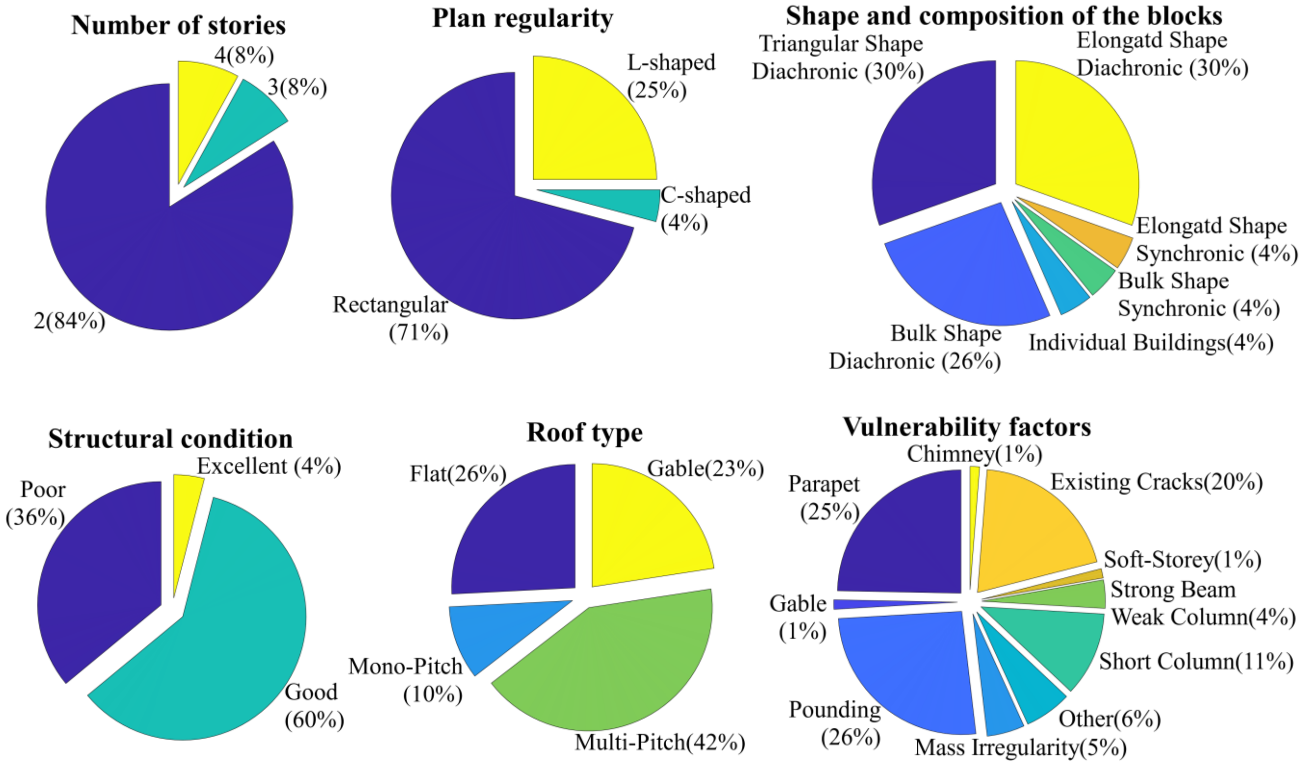

Figure 4. Statistics of the surveyed CH assets in Iloilo City.

Figure 5. Damaged columns: deep vertical cracks (left); concrete cover crushing (right).

Figure 6 (left) shows the computed INSPIRE indices. It is worth mentioning that the resulting indices values are arbitrarily categorized in three groups, respectively “green, yellow and red tags” by defining two threshold values for the various indices. The definition of such thresholds is essentially a subjective (often political) choice that shapes the 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.

Figure 6 (left) highlights the effect of the vulnerability factors, considered through the performance modifier, on the overall seismic risk prioritization index. Indeed, the baseline scores, indicated with grey bars in Figure 6, are fairly homogeneous due to the fact that the surveyed buildings have similar basic parameters; hence, the performance modifier plays a crucial role in differentiating the seismic risk prioritization indices for the various assets under investigation.

Figure 6 (center) shows the wind risk prioritization indices calculated with the SCOSSO approach. As mentioned above, the roof is the main vulnerability factor considered in the analysis. In this case, the SCOSSO index shows a higher variability if compared to the seismic risk prioritization indices; this is due to the variability of the geometrical and structural characteristics of the surveyed roofs.

Finally, the two indices are combined through the Square Root Sum of Squares (SRSS), and rescaled in order to have again a final risk prioritization index which varies in a range between 0 and 100% (Figure 6, right). A more detailed discussion on possible approaches to combine single-hazard risk prioritization indices to define multi-hazard risk prioritization strategies is discussed in Gentile et al., 2019. By comparing the partial indices with the combined ones, a higher of the results can be observed.

These results highlight the need for considering all the significant hazards affecting a particular building portfolio in the prioritization process. It should be noted that both the INSPIRE and the SCOSSO procedures, similarly to most of the risk prioritization approaches available in the literature, intrinsically assume a homogeneous value of the analyzed assets.

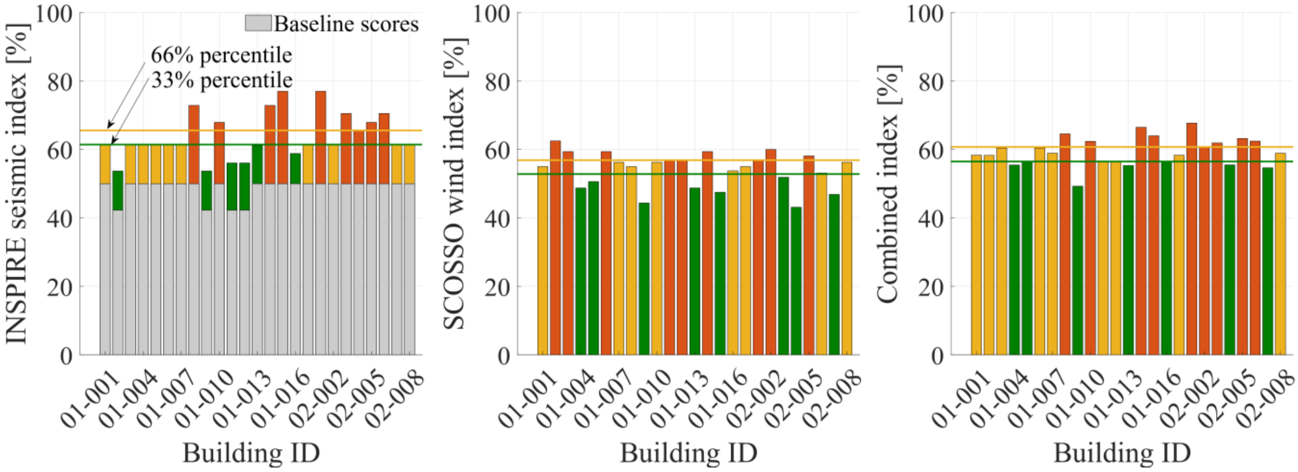

Figure 6. Risk prioritization indices: INSPIRE seismic index (left); SCOSSO wind index (center); combined multi-hazards index (right).

This assumption, which is usually valid for various asset typologies is not equally true for CH assets. Indeed, the value of the CH asset is determined by architectural and social factors, as discussed in *Section 1*. This particular feature of CH buildings should be included in the risk prioritization procedures in order to obtain a better estimation of the prioritization scheme. This is currently under investigation by the authors, which are further refining the procedure.

4 CONCLUSIONS

This paper presented a general overview and the preliminary results of the *Cultural Heritage Resilience & Sustainability to multiple Hazards* (CHeRiSH) project which proposes a multi-level, harmonized, and engineering-based risk and resilience assessment framework for Cultural Heritage (CH) assets in the Philippines exposed to multiple natural hazards. As a first step towards CHeRiSH's overall aim, this paper introduced an *ad-hoc* Rapid Visual Survey (RVS) form designed for CH assets. The main novelty of the proposed RVS form is in its multi-level architecture which allows improving the estimation of the structural fragility and risk once new detailed information is available. Special emphasis is placed on the use of new technologies for the survey of CH assets, such as drones, omnidirectional cameras, thermal cameras and photogrammetry. Their applications within the proposed framework was discussed, highlighting their main advantages and drawbacks. A suitable Building Information Modeling (BIM) platform for the management of the collected data is also proposed within the CHeRiSH project and was introduced in this work.

The proposed RVS form allows one to use existing approaches for the calculation of risk prioritization indices against different hazards. In particular, the INSPIRE seismic prioritization index and the wind prioritization index developed within the SCOSSO project were used in this work. The application of the proposed RVS form on the CH assets of Iloilo City, Philippines, showed the feasibility in practice of the proposed framework. Findings from the fieldwork highlighted the important role played by the widespread vulnerability factors, strongly affecting the performance of the surveyed CH assets. Combining the two indices allows one to define a multi-hazard prioritization scheme for more detailed structural analysis, and retrofitting/strengthening planning and conceptual design. However, incorporating the CH value within existing risk prioritization procedures is an essential next step within the proposed framework. This can be achieved, for instance, by considering both objective and subjective criteria, such as social impact, within a hierarchical scheme in order to define a "value" index which further modify the risk prioritization index against a selected hazard.

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