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# A MOBILE APPLICATION FOR MULTI-HAZARD PHYSICAL VULNERABILITY PRIORITIZATION OF SCHOOLS

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## ABSTRACT

This paper introduces a series of tools for a rapid yet reliable visual multi-hazard vulnerability prioritization of school infrastructure against potentially destructive natural hazards, i.e., earthquake, typhoon, and flood. The proposed tools can assist and speed up the process of identifying the most vulnerable school buildings for further decision-making. For each considered school, a set of parameters, including general information on the building and its occupants, structural and nonstructural characteristics, and secondary vulnerability modifiers, are first gathered. For each parameter, a vulnerability rating is assigned to its possible attributes, finally determining a vulnerability index for each considered school building exposed to earthquake, wind, and flood hazards. A mobile application has been developed for the entire process to assist the surveyors by increasing the efficiency and speed. The applicability of the proposed methodology and mobile application is tested by conducting an assessment of 115 elementary schools located in the city of Cagayan de Oro, Philippines. A statistical analysis of the gathered data along with the estimated vulnerability indices, allow the identification of the most vulnerable school buildings for more detailed structural analysis, and retrofitting/strengthening planning and conceptual design.

*Keywords: Multi-Hazard Vulnerability Assessment; Prioritization; School Infrastructure; Rapid Visual Survey; Mobile Application*

## 1. INTRODUCTION

The Philippines is among the top global disaster hotspots, and is exposed to a wide range of natural and man-made hazards, which is a limiting factor in its sustainable development. It ranks 8th among countries most exposed to multiple hazards (GFDRR, 2013). In the recent *Germanwatch Climate Risk Index* in 2017, the Philippines ranked 5$^{th}$ among the most affected countries by disasters, with 62% of Gross Domestic Product (GDP) in geographic areas at risk. Located in the Pacific Ring of Fire, it is highly exposed to earthquakes, volcanic eruptions, and other geological hazards, as well as to multiple typhoons and monsoon rains. An average of six tropical cyclones make landfall in the Philippines annually with another three-passing close enough to cause loss. Super typhoon landfalls occur, on average, twice every three years. Most of these occur along the relatively unpopulated eastern coast and thus wind risk, from a country perspective, is relatively low. Because of weak steering currents, storms tend to move slowly across the Philippines. As a result, heavy precipitation is very common and thus flood dominates the risk in the Philippines. For instance, it is not uncommon for more than 500 mm of precipitation to fall across a large area, with more than 1,000 mm having been observed across the mountains of Luzon.

In recognition of the country's vulnerability to natural disasters, the enactment of the Philippine Disaster Risk Reduction and Management (DRRM) Act in 2010 (Republic Act 10121) enabled substantial progress in shifting the emphasis from emergency response to preparedness, mitigation and prevention. Significant resources have been provided for ex-ante investments and new areas of engagement have been considered in the policy dialogue. However, challenges remain in enabling implementation of

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disaster risk reduction investments in priority sectors, including education. Schools play a critical role in the education of a community's next generation; school children are one of the most vulnerable components of the society due to their age and their developmental stage. A safer and resilient school can save valuable lives of children, provide a safe haven for the local community, serving as a temporary shelter and helping to bring normalcy back to society in times of disaster. However, like other infrastructure, public school buildings constructed prior to adequate building codes, share structural deficiencies common to other buildings of the same structural types in the same setting, but the above considerations set school buildings apart from their peers in terms of priority for assessment and resource allocation for retrofitting/strengthening plans.

Rapid Visual Screening (RVS) procedures have been developed and widely used in practice to identify, inventory, and screen buildings that are potentially vulnerable to multiple natural hazards. RVS procedures typically consists of methods and forms that help users to quickly rate and rank buildings according to their physical vulnerability. Once a building has been rated/ranked as highly vulnerable, it should be further assessed by trained and experienced personnel through further and more advanced (structural) analysis to determine its deficiencies and, if necessary, to recommend retrofitting/strengthening interventions or replacement/relocation. For instance, Federal Emergency Management Agency (FEMA) P-154 (2015) is dedicated to the Rapid Visual Screening of Buildings for Potential Seismic Hazards. The companion FEMA P-155 (2015) describes the technical background and process used in FEMA P-154, including the scoring system and its development, the revisions considered with respect to its previous editions, and conclusions reached. In particular, the first edition of FEMA P-154 was published in 1988, providing a procedure to evaluate the seismic safety of a large inventory of buildings quickly and inexpensively (with minimum access to the considered buildings), and determine hose buildings requiring a more detailed examination. In the first decade after its publication, the procedure was used by private-sector organizations and government agencies to evaluate more than 70,000 buildings in the United States. In 2014, FEMA automated the paper-based screening procedure of FEMA P-154 implementing it in a mobile application (ROVER - *Rapid Observation of Vulnerability and Estimation of Risk*), enabling users to document and transmit data gathered in the field.

In the past two decades, similar rapid surveying forms and fast procedures have been proposed by different authorities and organization, such as the World Health Organization (WHO) and the United Nations (UN), with several studies focusing on assessing public and private buildings in developing countries (e.g., Nepal and Kyrgyzstan), including schools. For instance, Dhungel et al. (2012) collected and assessed the physical condition of 1381 building units from 580 schools in Nepal. The data was collected by mobilizing the school teachers; school vulnerability was used to estimate the possible damage/casualties/injuries for earthquakes of different intensities. Similarly, a number of governmental departments worldwide, such as Alaska's Department of Education (1997) have produced surveying forms to assess the structural conditions of school buildings and the associate seismic vulnerability. The forms mainly consist of checklists investigating areas of potential concerns. A study conducted by Grant et al., (2007), proposed a prioritization scheme for seismic interventions in school buildings in Italy. Since it is not practical to carry out detailed assessment for around 60,000 Italian schools, the framework is a multiple-level procedure that aims to identify the highest-risk buildings based on filters of increasing detail, and reduces the size of the building inventory at each step. With respect to other natural hazards, Pazzi et al. (2016) assessed the safety of ten schools in Tuscany, Italy, against geo-hydrological hazards using a RVS method. The study proposes a geohazard safety classification (GSC) of schools and provides useful information to local decision-makers. The GSC is calculated integrating ancillary data by means of rapid and not invasive field surveys and questionnaires distributed to the school's employees. A study on flood vulnerability of historical buildings was conducted by Stephenson & D'Ayala (2014); while Womble et al. (2016) assessed the building against possible wind damage.

This paper introduces a series of tools for a rapid yet reliable visual multi-hazard vulnerability prioritization of school infrastructure against the most common natural hazards of the Philippines, i.e., earthquake, typhoon, and flood. The proposed tools have been developed as part of the SCOSSO project (Safer Communities through Safer Schools), funded by the UK Engineering and Physical Sciences

Research Council (EPSRC) Global Challenges Research Fund (GCRF). To this aim, a rapid visual survey form is developed first and implemented in a mobile application to efficiently assist the surveyors. An illustrative application of the developed tools is presented for the city of Cagayan de Oro, Philippines, relating the collected data for 115 school buildings to vulnerability indices to swiftly determine the most vulnerable structures among the surveyed stock. The overall aim is to prioritize more detailed data collection campaigns and structural assessment procedures (e.g., analytical vulnerability approaches, through fragility and vulnerability relationships), and ultimately to plan further retrofitting/strengthening measures or, if necessary, school replacement/replacement.

## 2. RAPID SURVEYING OF SCHOOL INFRASTRUCTURE

The proposed procedure uses a sidewalk survey of a school building and a data collection form, which the person conducting the survey can complete, based on visual observation of the building from the exterior (and if possible, the interior), without requiring detailed structural drawings or calculation reports. Hence, the parameters used in assessment have been chosen based on the importance and practicality of available and measurable data, while considering the time needed for each assessment. A one-page data collection form is proposed, as shown in Figure 1, including allocated spaces for documenting the general information on the building’s geolocation and identification, structural characteristics and deficiencies. Moreover, the blank space on the back of the survey form can be used to sketch the building’s shape and footprint. It should be mentioned that most of the options for categorizing the structural systems follows the recent Global Earthquake Model (GEM) Building Taxonomy (Brzev et al., 2013).

The collected data can be used for a quick assessment of the structural integrity and to assess whether the building is capable of resisting lateral and vertical loads resulting from seismic ground shaking and flood or typhoon pressure. Hence, information regarding the general structural characteristics should be collected, such lateral-load resisting system and its materials, age of construction, number and dimensions of columns and beams, type of foundation, presence and type of infill walls, type of openings and floor slabs, along with characteristics of the roof, etc. Furthermore, depending on the structural system and material, the most common deficiencies will be identified, particularly when looking at seismic vulnerability. These are referred to as vulnerability factors and for instance consider potential pounding effects, presence of soft-story, presence of strong-beams weak-columns, various irregularities, etc. A further investigation concerns the confidence of the collected data ranging from ‘high’ to ‘low’, measuring the confidence of the surveyor in collecting each of the input data during the assessment.

The main aim of the proposed form is to gain an acceptable understanding of how the building will perform under different hazards. Therefore, the visual survey includes some basic inquiries regarding the potential hazard and their extent of impact based on available resources. For instance, the form includes fields related to the distance of the school to the closest river basin and fault or the hazard categories according to the local design codes. The form also considers the exposure to some extents, estimated mainly based on the collected data regarding the number of classes and occupants.

The inspection time depends heavily on the foot-print of the surveyed building and can vary between 15 to 30 minutes, plus the traveling time spent between buildings. The preparation time and completing results to be ready for decision-making must also be considered. The collected data can then be easily categorized, assessed and reviewed through statistical methods. It is likely that, some percentages of buildings in any screening program, some aspects of the structure cannot be identified due to the architectural finishes covering them. In this case, a more detailed structural assessment can be performed to correctly identify the structural type and its deficiencies. However, the collected data can also be used for developing detailed numerical models with relatively high details, for instance through a simulated design procedure (Verderame et al., 2010).

SAFER COMMUNITIES
THROUGH SAFER SCHOOLS
**RAPID VISUAL SURVEY** [v.3]

SCOSSO

**General Info.**

| | | |
|---|---|---|
| Date: | Time: | Surveyor Name: |
| School Compound Name / Address: | | |
| Building ID: | | Total No. of Students in Building: |
| GPS Coordinate → Lat.: | Lon.: | |
| Position → [ ] Corner [ ] Mid-block [ ] End-block [ ] Isolated [ ] Other: | | |
| Construction Year: | [ ] Unknown | Confidence: [ ] H [ ] M [ ] L |
| Availability of Structural Drawing → [ ] NO [ ] YES **Sketch a Simple Building Plan on the back of this Sheet** | | |
| Any nearby Rivers → [ ] NO [ ] YES Distance: | | |
| Any nearby Coasts → [ ] NO [ ] YES Distance: | | |
| Any nearby Faults → [ ] NO [ ] YES Distance: | | |

**Building Info.**

| | |
|---|---|
| No. Storey : | Storey Height (m): |
| No. Bay X : | Total Length X (m): |
| No. Bay Y : | Total Length Y (m): |
| No. Rooms → Classroom: Library: Office: IT Hub: Hall: Services: Other: | |
| Dimension of Average Classroom (m) → X: Y: | |
| Dimensions of Largest Room (m) → X: Y: Info: | |
| No. openings per storey: | Largest opening size (m): |

**Structural Info.**

| | | Unk* | Confidence |
|---|---|---|---|
| **Material of Load-Resisting System** | [ ] Masonry [ ] Reinforced Concrete [ ] Steel [ ] Timber [ ] Other: | [ ] | H M L |
| **Floor Material** | [ ] RC Slab [ ] Timber Joists + Wooden Floor [ ] Reinforced Brick Concrete [ ] Other: | [ ] | H M L |
| **Roof Structural System** | [ ] RC Slab [ ] Timber Truss [ ] Steel Truss [ ] Reinforced Brick Concrete [ ] Other: | [ ] | H M L |
| **Roof Covering** | [ ] Tiles [ ] Metal Sheeting [ ] Other: | [ ] | H M L |
| **Roof Pitch** | [ ] Flat [ ] Mono Pitch [ ] Multi Pitch → No.: | [ ] | H M L |
| **Roof Condition** | [ ] Poor/Deteriorated [ ] Good/Fair [ ] Excellent/Brand New | [ ] | H M L |
| **Roof Connection** | [ ] Poor/Deteriorated [ ] Good/Fair [ ] Excellent/Brand New | [ ] | H M L |
| **Lateral Load Resisting System** | [ ] Frame [ ] Load Bearing Walls [ ] RC Shear Wall [ ] Bracing [ ] Confined Masonry [ ] Reinforced Masonry [ ] Combined [ ] Other: | [ ] | H M L |
| **Structural Condition** | [ ] Poor/Deteriorated [ ] Good/Fair [ ] Excellent/Brand New | [ ] | H M L |
| **Connection Quality** | [ ] Poor/Deteriorated [ ] Good/Fair [ ] Excellent/Brand New | [ ] | H M L |
| **Retrofitting** | [ ] No [ ] Yes → Info: | [ ] | H M L |
| **Modifications** | [ ] No [ ] Yes → Info: [ ] Addition of Stories: [ ] Extension of Plan: | [ ] | H M L |
| **Foundation Type** | [ ] RC [ ] Brick [ ] Stone [ ] Other | [ ] | H M L |
| **Vulnerability Factors (Indicate Confidence)** | [ ] Short column [ ] Pounding (if buildings closer than 0.2m) [ ] Soft storey [ ] Strong Beam-Weak Column [ ] Built on Slope [ ] Built on Stilts [ ] Balconies [ ] Plan irreg. [ ] Elevation irreg. [ ] Mass irreg. [ ] Opening irreg. [ ] Parapet [ ] Gable [ ] Other: | | |
| **If MASONRY:** | | | |
| **Masonry Type** | [ ] Masonry Brick [ ] Masonry Block [ ] Concrete Block [ ] Cut stone [ ] Adobe [ ] Rubble Stone [ ] Other | [ ] | H M L |
| **Mortar Type** | [ ] None [ ] Cement [ ] Lime [ ] Mud | [ ] | H M L |
| **Reinforcement** | [ ] No [ ] Yes | [ ] | H M L |
| **Confinement** | [ ] No [ ] Yes | [ ] | H M L |
| **Wall Thickness (m)** | | [ ] | H M L |
| **Wall Layer** | [ ] Solid [ ] Multi Leaf [ ] Cavity Walls | [ ] | H M L |
| **If FRAME [ RC, Timber, Steel ]:** | | | |
| **Beam Dimensions (m)** | | [ ] | H M L |
| **Column Dimensions (m)** | | [ ] | H M L |
| **Infill Wall Material** | [ ] Brick [ ] Concrete Block [ ] Timber Plates [ ] Adobe [ ] Other: Thickness (m): | [ ] | H M L |

*Unknown H = high, M = medium, L = low **Any extra comments can be added on the back of this sheet.**

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Figure 1. SCOSSO rapid visual survey data collection form

## 3. ILLUSTRATIVE APPLICATION

To test the applicability of the proposed data collection form, identifying its shortcomings, and potential improvements, the city of Cagayan de Oro (CdeO) in the Philippines is chosen as a case-study. CdeO is a highly-urbanized city, situated along the north central coast of the Mindanao island (8°29′N 124°39′E) and facing Macajalar Bay with 25 kilometers of coastline. According to the 2015 census, the city has a population of 675,950 and a density of 1,600/km2, making it the 10th most populous city in the Philippines.

Generally, the city is exposed to extreme weather conditions resulting in storms and flood. While CdeO lies outside the typhoon belt, it is affected by the inter-tropical convergence zone. In December 2011, the tropical storm Washi hit CdeO, with a formidable floodwater current sweptwing away mainly poor and socialized housing communities along river banks, leaving about 2,000 people dead or missing, and resulting in more than US$29.5M of damage (Sealza & Sealza, 2014). The recorded 24-hour rainfall (180.9 mm) at Lumbia, CdeO, exceeded its monthly average by 60%. Moreover, CdeO is relatively close to some major seismic faults and it experienced the 2013 Bohol earthquake.

A total of 115 school buildings have been visually surveyed in four days. All the surveyed structures are in elementary grade campuses in different locations of CdeO. A number of surveyed buildings are designated as shelters in case of any disaster. In each school campus, a mixture of buildings with various construction years, material, structural system, and function co-exists. As expected, a variation in the type of materials, workmanship and technology during the construction was observed, even in case of identical buildings. The structural type of the surveyed buildings ranges from masonry with timber roof to reinforced concrete (RC) framed structures, with steel trusses supporting the roof. The typical number of storeys range between one to four storeys, with a majority being single-story. The plan shapes in most cases varied from regular square to rectangular plan with a few rare cases being L-shaped. Most of the surveyed buildings were constructed after 2010, while a considerable number were from the 1990s.

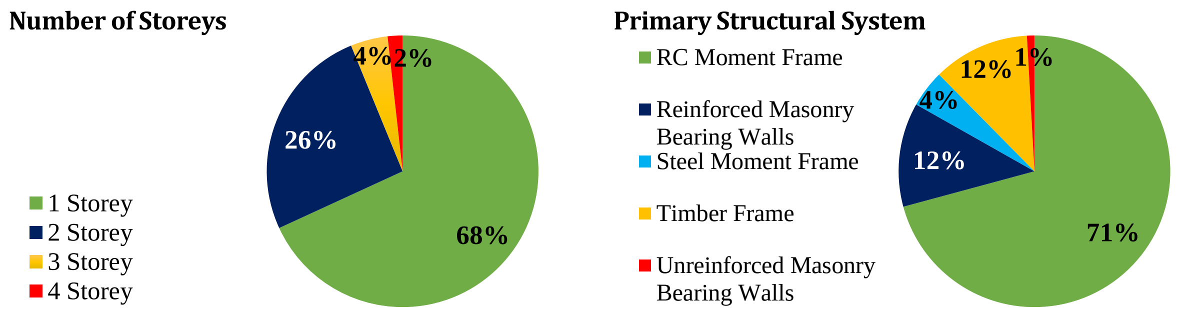


Figure 2. Statistics on number of stories and primary structural systems of surveyed schools in Cayan de Oro – Philippines

The construction year was obtained mainly from the school's registry documents or through interviewing locals. In a few cases (16%), the accurate built year could not be found and was indicated as unknown. As anticipated, signs of decay and poor structural conditions were observed in the structures which have been constructed over long periods of time. Statistical representations of the collected data on schools are illustrated in Figure 2 and 3.

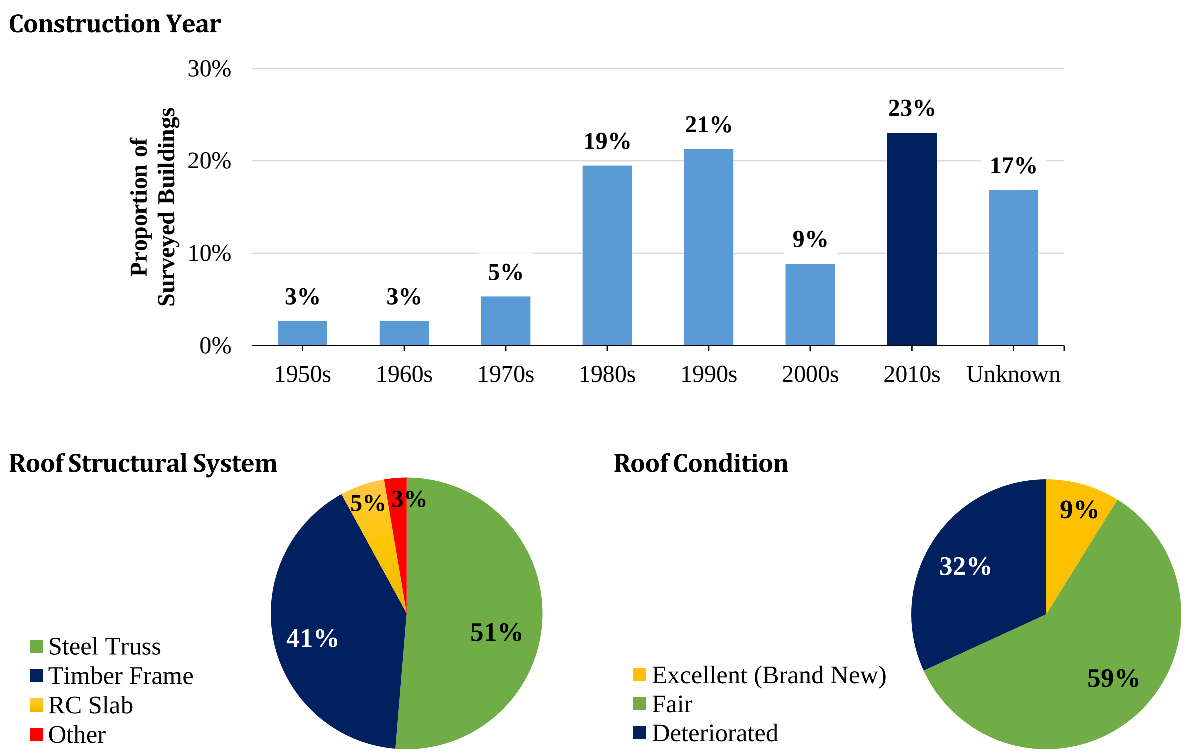


Figure 3. Statistics on construction year, roof structural systems and condition of surveyed schools in Cayan de Oro – Philippines

In most cases, the school buildings consist of rows of classrooms and a walkway in the longitudinal direction. Individual classrooms approximately measure 9m × 7m, with an approximate 3m wide walkway and typical floor height of 3m tall. The exposure assessment was mainly focused on the average number of student population per class, ranging from 40 to 50 pupils per classroom, considering the plan size and also the number of classroom per structure. According to the initial assessment of the collected data, the most typical school buildings consist of RC frames with infill walls. The infill walls are mainly built with hollow concrete blocks with minimal contact between the infill and its surrounding frame. The buildings generally have gable-pitched roofs of twenty to thirty degrees, with rafters anchored in steel or wooden trusses to resist lateral and vertical loads from typhoon and seismic activity. Based on the collected vulnerable factors, due to the regular rectangular shape, the majority of surveyed buildings (≈83%) are not susceptible to torsional effects. However, nearly half of the buildings (≈43%) are prone to pounding effect due to the close proximity to nearby structures.

## 4. VULNERABILITY INDICES FOR MULTIPLE NATURAL HAZARDS

Once the data collection phase is completed, and depending on the considered hazard, a subset of parameters with the highest contribution to the vulnerability can be identified (Table 1). Some of these parameters are shared among all hazards, such as the construction year or the structural system and its material, while some are just specific to a particular hazard. For instance, in case of strong wind, most of the roof characteristics have been included, while for the flood hazard, the percentage and dimensions of openings have a major effect. Similarly, the considered secondary vulnerability factors (e.g., presence of short columns, potential for pounding, presence of soft-story) are mainly relevant when assessing seismic vulnerability.

For each important parameter, a range of possible attributes can be identified and these can be assigned a vulnerability rating (VR) on a scale from 0 to 100. In most of the cases, the scale is divided into equal, unweighted parts according to the number of attributes, with that indicating the lowest vulnerability assigned the value of 0, and that indicating the highest assigned the value 100. The ranking of the attributes within each parameter takes into account their relative vulnerability for the specific hazards considered here. Such a ranking is based on engineering judgment and, for some parameters (e.g., lateral load resisting system and its material), on an analytical calibration based on fragility and vulnerability relationship. For instance, the construction year of the building plays a critical role in the vulnerability assessment. In case the building has been designed and built recently, there is high chance that some hazard-informed design and some ad-hoc resistance measures have been considered and implemented. Hence, the allocated vulnerability rating for recent construction years will be lower compared to that of older building designed based on earlier building codes.

Table 1. Factors allocated for estimating the vulnerability index according to the hazard

<table>
<tr><th>FLOOD</th><th>EARTHQUAKE</th><th>WIND</th></tr>
<tr><td colspan="3">Material + Lateral System Combination</td></tr>
<tr><td colspan="3">Construction Year</td></tr>
<tr><td colspan="3">No. of Story</td></tr>
<tr><td colspan="3">Structural Condition</td></tr>
<tr><td>% of Opening</td><td>Floor Material</td><td>Roof Structure</td></tr>
<tr><td></td><td>Connection Quality</td><td>Roof Covering</td></tr>
<tr><td></td><td>Vulnerability Factors</td><td>Roof Connection</td></tr>
<tr><td></td><td></td><td>Roof Condition</td></tr>
<tr><td></td><td></td><td>Roof Pitch</td></tr>
</table>

The vulnerability ratings for each of the considered parameters are combined to determine an overall vulnerability index (VI) assigned to a given building, i.e., a normalized, weighted average of the assigned rates to each important parameter. Details on the rating system and calculation of VI are discussed in detail in Nassirpour et al. (2017).

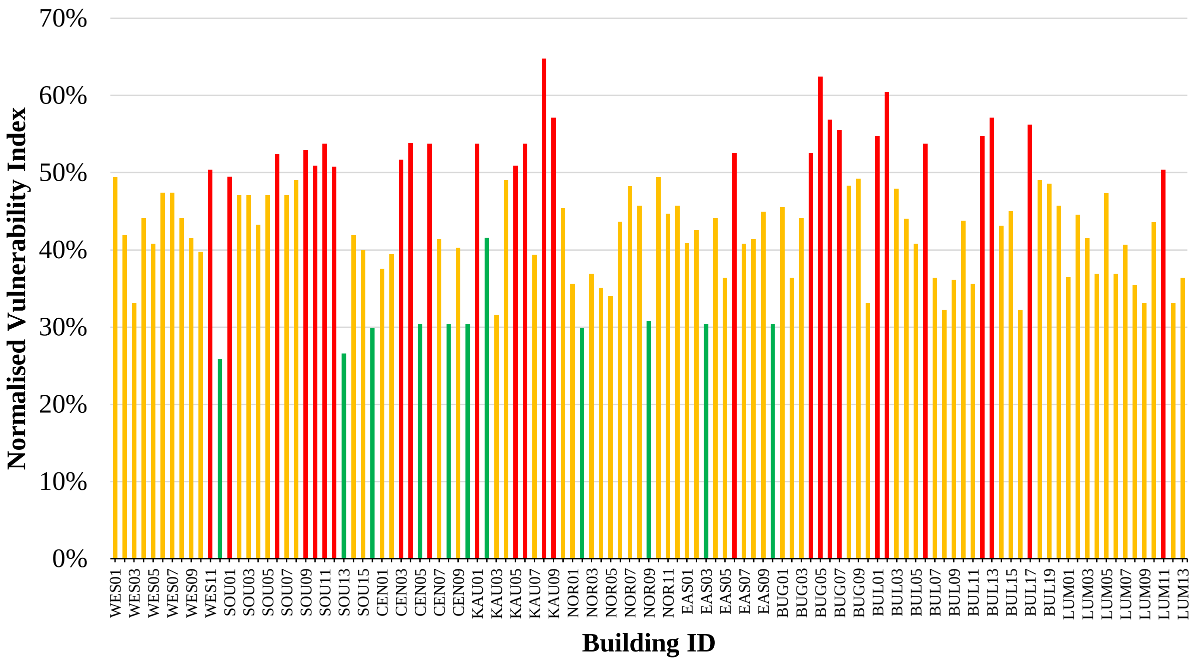


Figure 4. Vulnerability Index of 115 Surveyed Schools in Cayan de Oro – Philippines

As shown in Figure 4, 26 structures (22.6%) have high overall vulnerability (VI>50%), hence any more detailed structural assessment and retrofitting/strengthening planning should be prioritized for these buildings. The number of schools with moderate vulnerability is 78 (67.8%), while only 11 schools (9.56%) are characterized by a vulnerability index lower than 30%. Accordingly, the most vulnerable surveyed structure is KAU08 (VI = 64.8%), i.e., a highly deteriorated masonry structure with unreinforced bearing walls, built in 1983, and located in Kauswagan Central School (Figure 5-left). Similarly, BUL02 (VI = 60.5%; Figure 5-right) is a timber frame, single story, built in 1985, consisting of one classroom (9m × 4.8m) with timber supports for its roof. The general condition of the structure as well as its roof and the connections have been described deteriorated. In both cases, the buildings were susceptible to pounding effect and short column.


Figure 5. left: Kauswagan Central (ID: KAU08), right: Bulua Central (ID: BUL02)

On the other hand, the structure with the lowest vulnerability index (VI = 26%) is an isolated, brand new steel frame building in West city central school compound (ID: WES12). The building consists of two storeys (25.6m × 6m) and four classrooms in excellent condition and no report on obvious deficiencies (Figure 6-left). Similarly, a RC building, located in south city central school complex scored a vulnerability index of 29.9% (Figure 6-right).

Figure 6. left: West City Central (ID: WES12), right: South City Central (ID: SOU16)

The building was built in 2012, consists of two floors and two classrooms with a steel truss roof. According to the collected data, the building is in an excellent condition with high-quality connections between the columns and the roof and no visible deficiency is observed.

Figure 7, illustrates the individual VI values estimated for the discussed buildings with respect to each hazard and the average value.

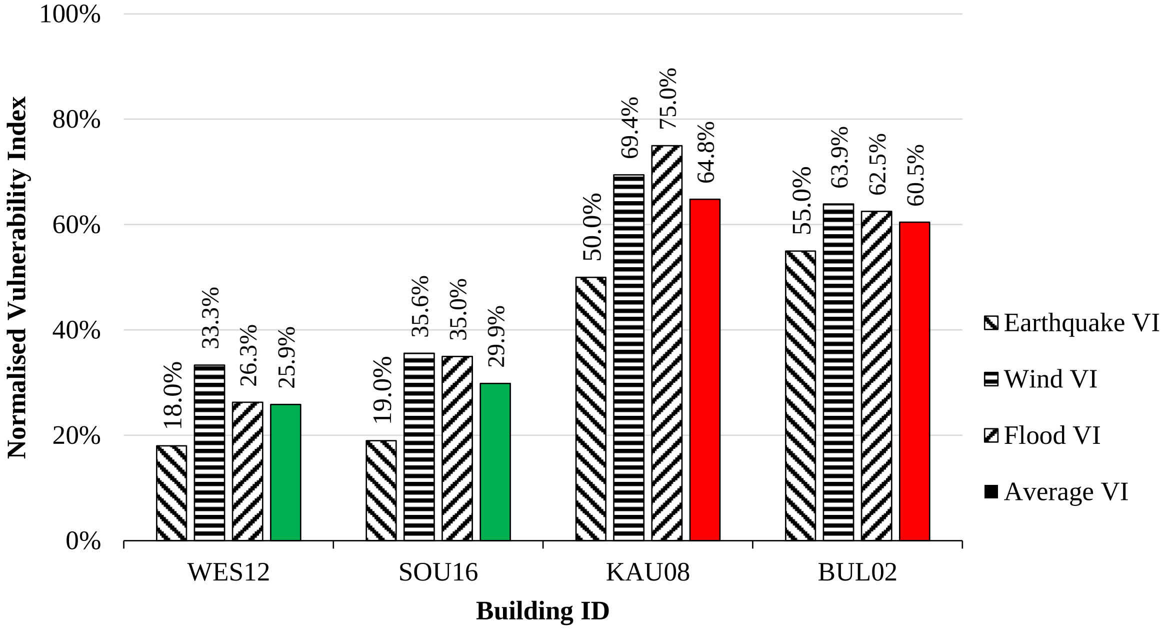


Figure 7. Evaluated vulnerability index of buildings based on the different hazards

A mobile application, SCOSSO App, has been developed to assist the surveyors by increasing the efficiency, precision and speed of the rapid visual survey. The discussed surveying form has been implemented completely in the application, featuring a simple and user friendly interface. The app is capable of evaluating the physical vulnerability of the surveyed buildings in real time for different hazards, including earthquake, flood and strong wind. Users can capture photos of the surveyed structures through the app, as it automatically allocates them to the relevant survey data. The surveying data is stored in the device and the cloud and can be easily shared via email or extracted as .csv file. Beside the traditional latitude and longitude location indicator, a built-in locator with a high precision of 3m in 3m is also included by implementing the What3Word extension (https://what3words.com/). Furthermore, a comprehensive offline surveying guide is provided, demonstrating different aspects and options of the app through visual examples. The SCOSSO mobile application is freely available through the Google Play Store (Figure 8).

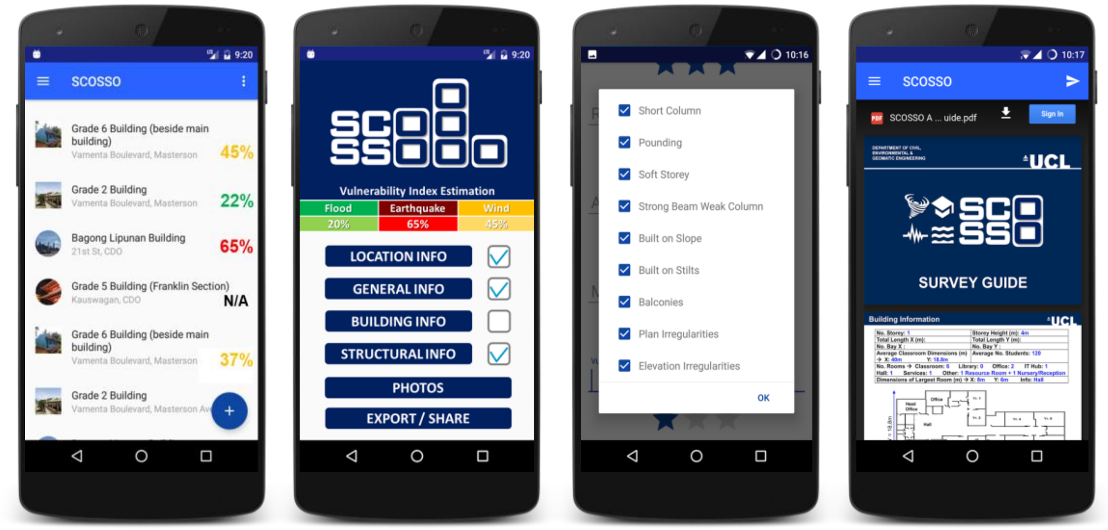


Figure 8. Interface of SCOSSO Mobile Application

## 5. CONCLUSION

Multi-hazard vulnerability prioritizing of 115 school buildings in the city of Cagayan de Oro, Philippines, has been assessed. To this aim, a data collection form is first proposed for rapid visual surveying of school buildings, considering the general information of the building and its structural characteristics. The collected parameters have been categorized according to their degree of importance and a vulnerability rating is assigned to each of the parameters with the highest contribution. A combined vulnerability index is finally derived. The proposed vulnerability rating method proves to be a relatively reliable approximate method for estimating the vulnerability of structures based on data collected from rapid visual survey. The applied rating system is designed to be implemented without performing complicated structural analysis. By identifying the most vulnerable cases, further detailed investigations can indicate whether the structures need retrofitting/strengthening or a replacement/relocation strategy is necessary.

Furthermore, a mobile application has been developed based on the discussed rapid visual surveying form and the proposed simplified physical vulnerability estimation method. The app can assist the data collection process by increasing the efficiency, precision and speed of the rapid visual survey.

## 6. ACKNOWLEDGEMENTS

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