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Seismic screening and structural investigation of heritage buildings for adaptive reuse: a survey study at Iloilo City, Philippines

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Abstract. Building adaptive reuse has been a popular strategy for cultural heritage conservation of structures for it serves two basic objectives of preserving heritage structures and promoting cultural heritage and tourism. Adaptive reuse is the adaptation of an old structure to allow the introduction of a modern function into the old structure. Old buildings are not demolished but recycled into modern uses. This strategy, however, needs a careful and thorough assessment of these existing heritage buildings to assure their resilience and sustainability to future hazards. Heritage buildings for adaptive reuse due to age and structural deterioration are highly vulnerable to hazards like earthquakes. Moreover, these buildings when used for commercial purposes may be subjected to additional loads due to changes in function. Considering the age of the structure, conformity to new design codes, additional loads imposed by unit modification, and the new function brought about by adaptive reuse of these structures, there is a need to assess these buildings to assure their safety and continuous use. Promoting adaptive reuse of heritage buildings and tourism is most appropriate in heritage zones like Calle Real in Iloilo City, the site for the case study. This paper presents a rapid seismic screening of buildings to prioritize a population of heritage buildings in a heritage zone for further detailed inspection. A site survey of the buildings was conducted at the heritage zone of Calle Real, Iloilo City in terms of their current use, and current condition to determine potential structural, maintenance, and functional issues related to resilience and to recommend future improvements in the implementation of adaptive reuse of heritage structures in cities and towns to assure their sustainability.

1. Introduction

Heritage buildings pose as important landmarks not only to add character with their beauty and traditional designs but also to display the history of a society long past and now inherited by the current generation. Heritage buildings contribute greatly to the surrounding society in different aspects by simply existing in the modern era. Heritage buildings, because of their importance with respect to a country’s culture and history must be preserved. Conservation of heritage structures allows them to retain their significance as a historical landmark while proving their worth economically and environmentally through reuse. However, heritage buildings suffer deterioration, alteration, and other forms of degradation and changes throughout its life like any other existing structure.

There are several ways to conserve and preserve heritage structures. Preserving a population of heritage structures is best applied in heritage zones where adaptive reuse is promoted. Adaptive reuse is utilizing a heritage structure for a different purpose from what it was originally built as to not become unproductive. This method allows old buildings to be recycled instead of having to build new structures

(Commonwealth of Australia, 2004). Aside from using the heritage buildings as museums, these buildings can be used for various purposes such as commercial, educational, or office. However, before adaptive reuse can be used on structures such as heritage buildings, rules and regulations set by a country's heritage laws about these buildings must be observed and followed.

In the Philippines, the Republic Act 10066 (RA 10066), or the National Cultural Heritage Act of 2009, defines adaptive reuse as using the buildings, built-in structures, or sites for a different purpose than originally intended. This would allow buildings or sites with intrinsic value to be conserved and maintain their engineering integrity and design. Any conservation attempts must go through the appropriate channels, and the cultural agency is responsible for the supervision and approval of the procedures and materials. Adaptive reuse is a common conservation option for buildings marked as cultural property, either being over fifty (50) years old or stated by the Commission. Aside from buildings, adaptive reuse is also implemented on an entire site marked as Heritage Zones, sites holding cultural significance. These Heritage Zones are maintained by the local government. The culture agency is responsible for issuing a Cease-and-Desist order should any significant modification on the cultural property pose a threat to the integrity of the property (Philippines, 2009). Iloilo City has a City Ordinance No. 00-054, declaring certain building structures or sites in Iloilo City (e.g. Calle Real) as a local heritage zone. Any form of modification (repair, rehabilitation, restoration, or construction) is prohibited without a recommendation from the Iloilo City Cultural Heritage Conservation Council (ICCHC).

Conservation of heritage structures allows them to retain their significance as a historical landmark while proving their worth economically and environmentally through reuse. However, heritage buildings suffer through deterioration, alteration, and other forms of degradation and changes throughout its life like any other existing structure. Assessment of existing structures has become a regular occurrence to determine their value economically, environmentally, and socio-politically. However, these assessments are in accordance with advanced methods that have yet to be realized in the traditional codes that the heritage buildings complied with. Due to this update in several provisions, heritage buildings must be assessed and verified for their structural reliability using current codes, with the old codes only present as guidance. Any change brought on the structure must abide by the current codes. Additionally, structural behavior should be investigated for ultimate and serviceability limit states to foresee the degree of deterioration on the building (Holicky & Sykora, 2012). According to their study, several issues that are evaluated are the following: new structural members added to existing load-carrying system due to rehabilitation; load resistance upon any change in use of the facility, operational changes, or extension of its design working life; the damage suffered from time-dependent deterioration, earthquake, and other effects; and other concerns that affect actual reliability of the heritage structure.

Preserving heritage structures in heritage zones is a challenge to the building owners, cultural advocates, and local government officials. This study was conceptualized to support the local government's policies in preserving heritage structures. Issues that need to be addressed include assessing the asset value of the heritage buildings, investigating the structural vulnerability of the buildings to hazards like earthquakes, wind, fire, and strengthening and retrofitting of these buildings to assure their resilience and sustainability. To accomplish these tasks, there is a need to conduct prioritization and screening of the existing buildings in the heritage zone using rapid screening and risk assessment of the site and the buildings. For this paper, seismic risk assessment and structural investigation were conducted at Calle Real, Iloilo City to demonstrate the challenges and issues on heritage preservation of buildings for adaptive reuse considering seismic hazards.

2. Multi-hazard risk assessment

Heritage buildings because of age and deterioration are at great risk of being damaged due to their vulnerable state and the hazards surrounding them. With limited budget and resources, it is a problem to preserve a great number of buildings simultaneously. Hence, a rapid risk assessment of these buildings due to natural hazards (earthquake, wind, flood) and man-made hazards (fire, terrorism) will guide decision-makers like LGUs, cultural heritage councils, architects, and engineers to rank and prioritize the buildings that must be given immediate attention for detailed structural assessment and retrofitting.

The multi-hazard risk assessment methodology developed for this study is based on the relationship among the parameters: Asset (A), Hazard (H), Vulnerability (V), and Risk (R) as shown in figure 1.

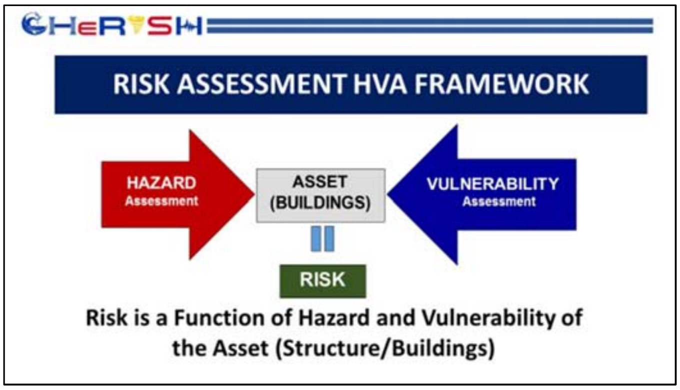


Figure 1. Risk Assessment Framework.

At the center of the risk assessment framework is the "Asset" which is the heritage structure or building in this study. An asset has a value that can be determined qualitatively or quantitatively by considering the relative importance of the heritage building in terms of architectural, historical, commercial, tourism, and adaptive reuse values.

"Hazard" is a "potentially damaging physical event, phenomenon or human activity that may cause losses in life or injury, property damage, social and economic disruption or environmental degradation" (UNISDR 2015). Natural hazards include earthquakes, typhoons, flood, tsunami, landslide, storm surge, drought, volcanic eruption, while human-induced hazards include terrorism, fire, war, and industrial catastrophe. Hazard assessment aims to determine the impact of a hazard to an asset by considering quantitative parameters that contribute to the degree of severance of the hazard like the size of the hazard (e.g. earthquake magnitude, peak ground acceleration, wind speed, precipitation, flood depth) and amplifying factors of the hazard (e.g. nearness to the fault, rivers or slopes, soil type).

"Vulnerability" refers to the "conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards" (UNISDR 2015). With respect to structures, vulnerability is the degree of susceptibility of the structural and non-structural elements of the building to specific hazards. A qualitative and semi-quantitative vulnerability assessment aims to assess if a building has vulnerable elements to a specific hazard. A building that possesses many vulnerable elements has a greater "risk" to perform poorly to the specific hazard. All in all, the risk (R) is determined using the general relationship below,

$$R = (H \times V) \times A \tag{1}$$

where R, H, V, and A are indices corresponding to the risk, hazard, vulnerability, and asset value, respectively; the latter three indices are referred to as *sub-indices*.

3. Qualitative/semi-quantitative risk assessment

The sub-indices are each defined by a cluster of key parameters, rated through a rapid visual screening (RVS) procedure. RVS is a first-level screening method that involves a quick visual inspection of key critical parameters of the structure. The key parameters for each index are rated high, medium, or low risk, corresponding to a score of 3, 2, or 1, respectively. The *weighted sum* of the relevant parameters will return the value of the sub-index in the study. Equation 1 is then used to compute the main risk index.

The methodology which is a modified version from Yu and Oreta (2014) uses the conventional technique of risk assessment (Vicente, Mendes Da Silva, & Varum, 2005). This technique returns a vulnerability index without estimating the corresponding damage. The corresponding weights for each key parameter under hazard, vulnerability, and asset can be determined through the conduct of an analytic hierarchy process (AHP) survey which is a pairwise comparison of all possible parameter combinations. Experts in the field are asked to choose the relative weight of each pair of parameters over a nine-point scale then they are aggregated by geometric mean before the calculation of weights.

This method is known as aggregation by individual judgments (Angiz, Mustafa, Noraida, & Kamil, 2012).

4. Seismic risk assessment

4.1. Seismic hazard parameters

The strength of the seismic event is measured through three key parameters: (1) distance of the study location to the nearest fault, (2) peak ground acceleration (PGA), and (3) soil conditions. Altogether, the three parameters aim to encapsulate the size and amplifying factors of the earthquake ground shaking at the site. The earthquake magnitude and seismicity are important seismic parameters, but the PGA best represents the local effect of the earthquake ground shaking at a site. The hazard rating is the sum of the weighted product of the scores of the hazard parameters.

4.2. Seismic vulnerability and modifier parameters

The vulnerability parameters, including its modifiers, aim to measure the relative capacity of a structure through the identification of "weak points". The number of weak points will determine the structure's capacity. The key vulnerability parameters are code year which is related to the age of structure (V1), plan irregularity (V2), vertical irregularity (V3), building proximity which is a provision for seismic gap (V4), number of floors (V5), structural system material (V6), number of bays in the transverse axis (V7), and column-to-column spacing (V8).

The vulnerability rating is the sum of the weighted product of the scores of the vulnerability parameters. The vulnerability rating is then further modified through time deterioration and structural modifiers (M). The modifiers, based on a report from the Architectural Institute of Japan (n.d.), adjust the vulnerability index through consideration of cracks, deflections, building age, continuity of the force load path, and material deterioration among others. Hence, the sub-index vulnerability, V, is multiplied by the modifying factor (M).

4.3. Seismic hazard risk index

The product between the hazard rating (H) and structural vulnerability rating (V), given as HxV, represents a hazard-based risk index. The seismic risk classification of low, medium, and high is used to group the buildings based on seismic risk.

The risk index of the heritage building considering the asset value can then be multiplied by the hazard risk index to obtain the final risk seismic risk index as R = A x H x V.

Figure 2. Villanueva Building (01-008), one of the CH structures in Calle Real

5. Pilot study in Calle Real, Iloilo City

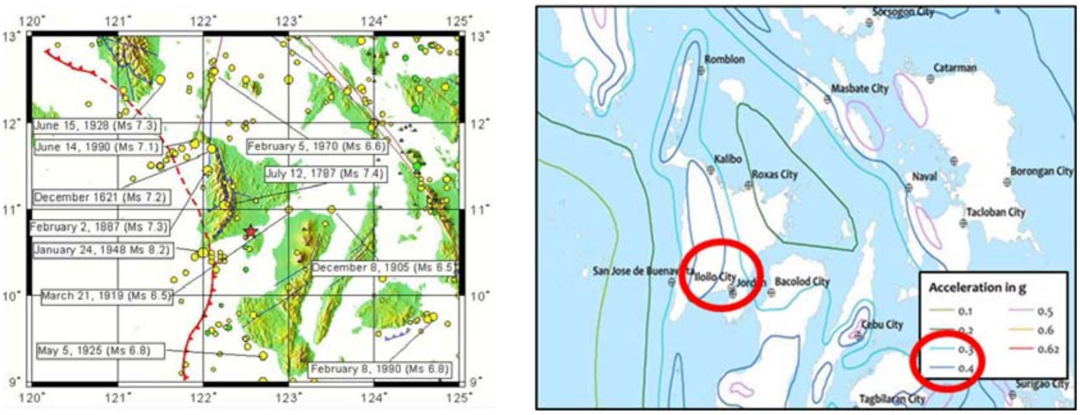
The City of Iloilo is situated in the central part of the Philippines. It is one of the oldest cities and has witnessed one of the first establishments of Spanish colonial rule. Calle Real, the downtown central business district (CBD) of the city at present hosts a total of thirty-one (31) identified heritage buildings. These structures were houses, of art deco architectural type (see figure 2), of the Illustrados (educated Filipino class), and trading bazaars of the entrepreneurial Chinese during the Spanish era (Table 1). Calle Real bounded by J. M. Basa, Aldeguer, Guanco and Iznart, and Mapa streets was declared by the National Historical Commission of the Philippines as a district and a heritage zone on August 8, 2014. It is by Ordinance No. 00-054, also known as the Local Cultural Heritage Conservation Ordinance which established the Iloilo City Cultural Heritage Conservation Council (ICCHC). The government and the Iloilo Cultural Heritage Foundation, Inc. (ICHFI) partnered for the restoration of the heritage structures. Recent efforts from the city government have demarcated the CBD as a cultural hub and regulated the preservation of such structures. The city has also instituted a cultural heritage conservation council to oversee preservation regulations (Yu, Oreta, Ibabao, & Hechanova, 2013). Through the council, several renovations of the heritage buildings have been undertaken to preserve the buildings. In line with these efforts, the identified heritage buildings were subjected to the developed methodology for heritage buildings. Only twenty-three buildings of the thirty-one (31) buildings listed in Table 1 were assessed for seismic risk since two of the buildings were burned down while the six (6) others were not listed yet at the time of this research. The number of identified heritage buildings on the CBD Heritage Zone will continue to increase as many of the buildings in that area will turn 50 years old in years to come.

Table 1. Calle Real Cultural Heritage Structures' List.

#	Building Code	Building Name	Vulnerability rating							
			V1	V2	V3	V4	V5	V6	V7	V8
1	01-001	Celso Ledesma	0.16	0.11	0.12	0.32	0.27	0.44	0.13	0.36
2	01-003	Pilar	0.16	0.11	0.12	0.32	0.27	0.44	0.25	0.18
3	01-004	Javellana	0.16	0.11	0.12	0.32	0.27	0.44	0.13	0.18
4	01-005	Iloilo Lucky Supply	0.16	0.11	0.12	0.32	0.27	0.44	0.38	0.36
5	01-006	S. Villanueva	0.16	0.11	0.12	0.32	0.27	0.44	0.25	0.18
6	01-007	Villanueva	0.16	0.33	0.12	0.32	0.27	0.44	0.13	0.18
7	01-008	Villanueva	0.16	0.33	0.12	0.32	0.27	0.44	0.25	0.18
8	01-009	Divinagracia	0.05	0.11	0.12	0.32	0.27	0.44	0.25	0.18
9	01-010	S. Javellana	0.16	0.33	0.35	0.32	0.27	0.44	0.13	0.18
10	01-011	Iloilo Central Trading	0.16	0.11	0.23	0.32	0.27	0.44	0.25	0.18
11	01-012	Regent Arcade	0.16	0.11	0.35	0.32	0.27	0.44	0.13	0.18
12	01-013	Elizalde	0.16	0.22	0.23	0.21	0.27	0.22	0.25	0.18
13	01-014	Magdalena	0.16	0.11	0.12	0.32	0.27	0.44	0.25	0.18
14	01-015	S. Villanueva	0.16	0.11	0.35	0.11	0.27	0.44	0.25	0.18
15	01-016	S. Villanueva	0.16	0.33	0.12	0.21	0.27	0.44	0.38	0.18
16	01-018	Villanueva	0.16	0.33	0.23	0.32	0.27	0.44	0.13	0.18
17	02-001	Villanueva	0.16	0.33	0.12	0.32	0.27	0.65	0.38	0.18
18	02-002	Villanueva	0.16	0.33	0.35	0.32	0.27	0.44	0.38	0.18
19	02-003	S. Villanueva	0.16	0.11	0.12	0.32	0.27	0.44	0.13	0.18
20	02-004	Iloilo Central Market	0.16	0.22	0.23	0.32	0.27	0.44	0.38	0.18
21	02-005	J. Melliza	0.16	0.33	0.23	0.32	0.27	0.44	0.38	0.18
22	02-007	LJ Hormillosa	0.16	0.11	0.23	0.32	0.27	0.44	0.38	0.18
23	02-008	L.J. Hormillosa	0.16	0.22	0.23	0.32	0.27	0.44	0.13	0.36
Average			0.16	0.20	0.19	0.30	0.27	0.44	0.25	0.20

5.1. Seismicity of Iloilo City

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) lists the city under seismic zone 4 in the seismic map of the Philippines (National Structural Code of the Philippines, 2010). A fault map from the PHIVOLCS shows that there are around three active faults in the proximity of the city.



(a) (b)

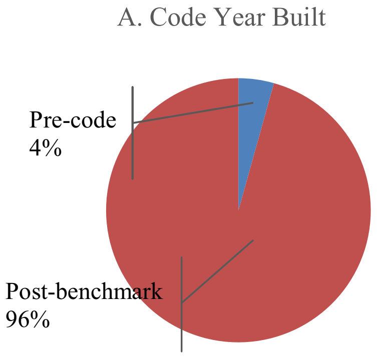
Figure 3. (a) Documented seismic activities in the Western Visayas Region. (b) PGA map from the Philippine Earthquake Model (PHIVOLCS).

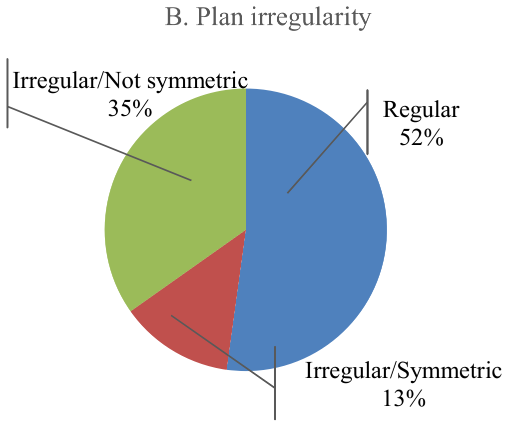
Historical earthquakes of the city with magnitudes six and above are plotted on a map; see Figure 3a (Bautista M. et al, 2012). The red star is the location of the city. Figure 3b shows a PGA map for a 500-year return period on a rock site determined by PHIVOLCS. The PGA for Iloilo ranges from 0.3g to 0.4g.

5.2. Seismic Rapid Assessment Result at Calle Real, Iloilo City

The seismic hazard ratings in this research are categorized into fault distance (H1), earthquake peak ground acceleration (H2), and soil foundation (H3). Earthquake peak ground acceleration (H2), and soil foundation (H3) are the highest factors that contribute to the hazard and fault distance (H1) being the least factor. The hazard ratings for these parameters are assumed to be the same for all the 23 cultural heritage (CH) structures in Calle Real since these buildings are relatively close to each other in the heritage zone. In the seismic risk assessment tool, the level of risk values for H1, H2, and H3 are 1, 2, and 2 respectively for each building. With equal weight given to these 3 parameters, a total hazard rating (H) of 1.67 is computed and thus used for all assessed structures.

Table 1 shows the structural vulnerability results under seismic vulnerability assessment. Specifically, the table presents the vulnerability rating and its average value for each parameter for all buildings. The structural system material (V6), pounding effect (V4), and building height (V5) respectively, were revealed to be the main parameters of the buildings that are most vulnerable to earthquake.





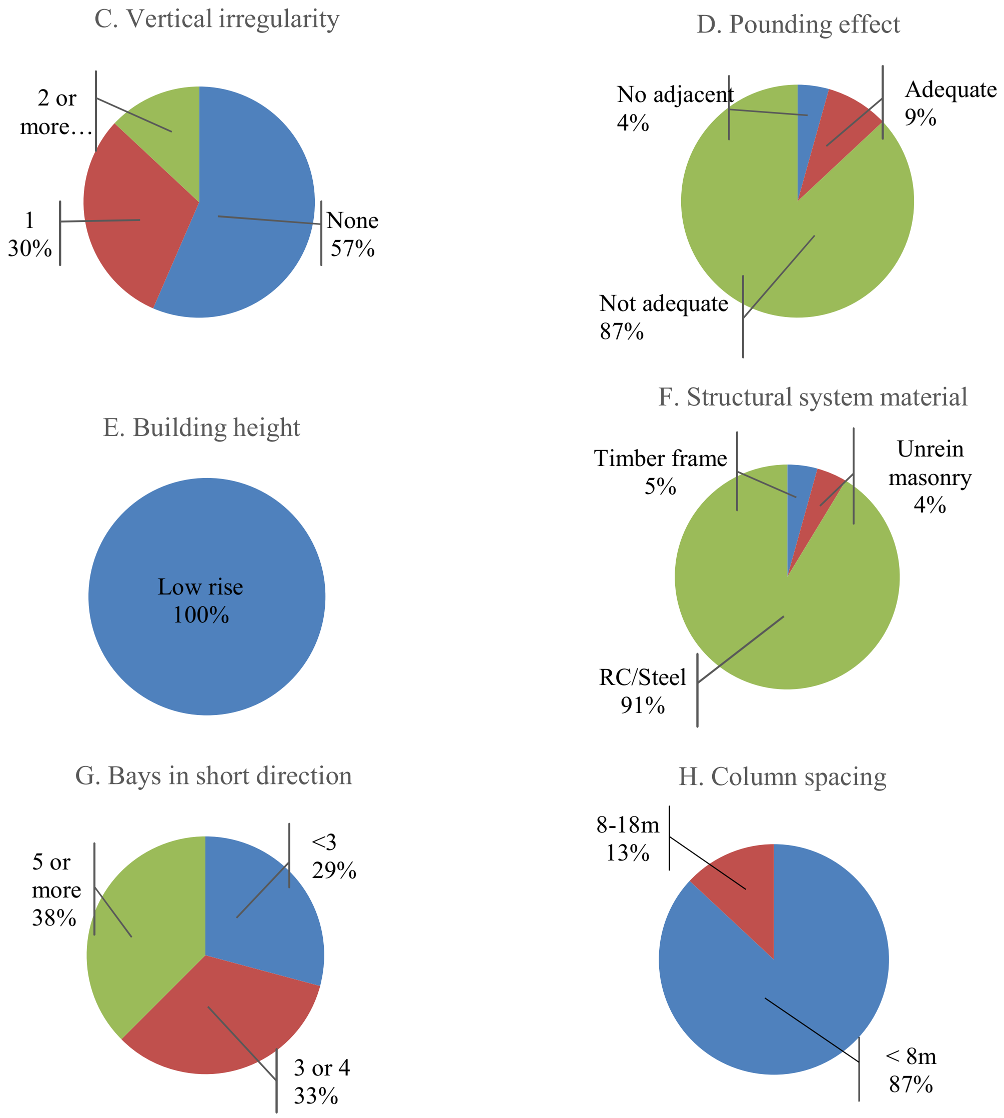


Figure 4. (A-H) Compiled pie charts for seismic vulnerability factors (Sevieri et al, 2019).

The distribution of seismic vulnerability factors for CH structures in Calle Real is graphically represented in figure 4 (compiled seismic vulnerability factor charts). All structures can be considered low-rise with 91% being constructed from reinforced concrete material. Moreover, 95.7% of structures were constructed before the adoption of building code with 47.8% of structures having plan irregularity, and 44.4% having vertical irregularity. Most of the buildings were subjected to a pounding effect (87%).

Figure 5 shows the statistics for seismic vulnerability modifiers. All buildings did not exhibit significant inclination as judged through a street survey. Also, all twenty-three (23) buildings had not been exposed to fire. However, all buildings somehow had used the whole or a portion of flooring for storage. Many of the structures had visible deformations, had shown leaks on walls and columns, and had exhibited cracks on structural members. Severe deterioration can also be observed from the finishing of both the exterior and interior parts of the structures. Finally, many of these structures had installed an additional floor/mezzanine for additional storage.

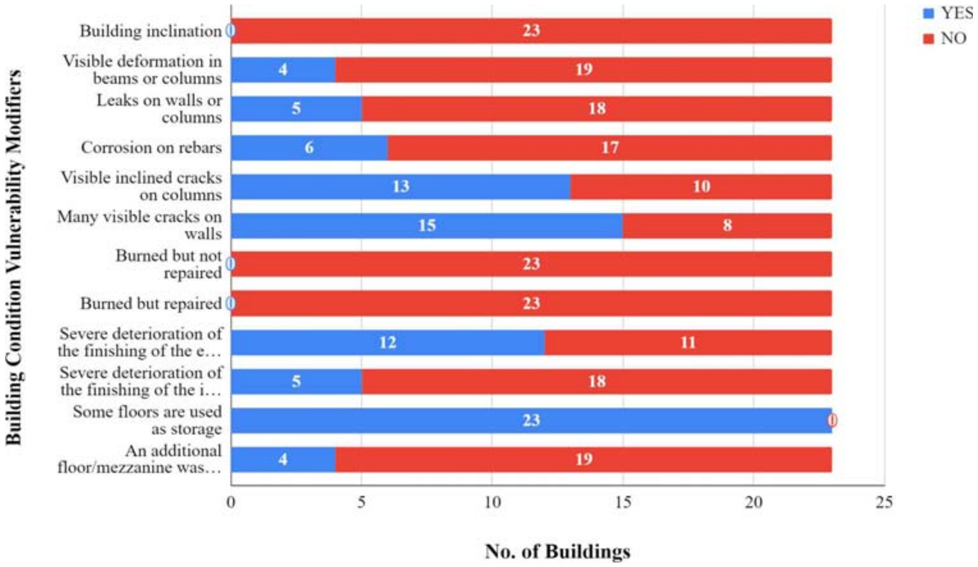


Figure 5. Building Condition Modifiers.

In the seismic risk index of figure 6 and seismic risk map in figure 7, it is seen that the 02-002 Villanueva is the most at-risk building with a seismic index of 6.78 classified under high risk. On the other hand, the building with the lowest risk as its index is only 3.38 is the 01-003 Pilar building classified as medium risk.

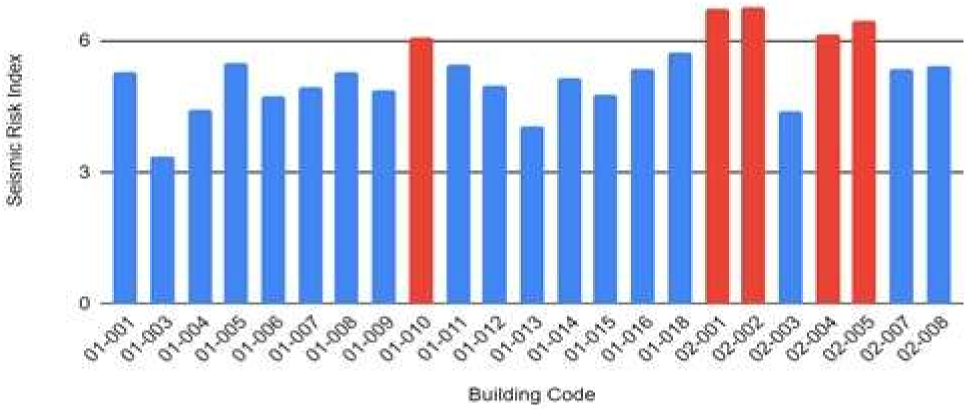


Figure 6. Seismic risk index.

Among the 23 assessed buildings, five (5) heritage structures are at high risk while the rest (18) are at medium risk. The seismic risk index ranges from 3.38 to 6.78. Five buildings that are found to be at high risk shared the same highest rating criteria which is the structural system material (V6). Twenty-one (21) out of twenty-three (23) buildings scored 0.44 or medium risk since the beams, columns, and girders of the buildings are mostly made up of reinforced concrete. This is estimated to contribute to 21.89% of the average vulnerability rating.

6. Site survey of Calle Real

During the site survey, several functional and structural issues were found in cultural heritage structures in Calle Real. Structure owners, to maximize earnings from their property with the least expense, put their property up for commercial lease based on the as-is condition of the structure. Since Calle Real is one of the busiest commercial areas in Iloilo City, rental fees are significantly high and as a result, tenants have imposed modifications on the structure to maximize the usable commercial space of the structure. Some of these modifications are conversion of spaces for storage, installation of the mezzanine for additional storage area (figure 8a), removal of a building component (e.g., column) to increase commercial space, installation of billboards on top of the structures (figure 8b), conversion of entire 2nd floor to storage, and cutting off a portion of roof for other purposes.

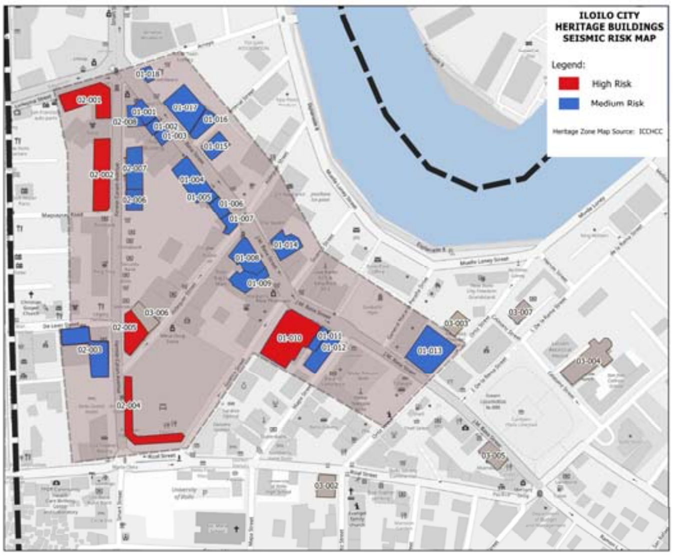


Figure 7. Seismic Risk Map of Calle Real

Figure 8. (a) Installation of mezzanine; (b) installation of billboards on top of the structure

Issues about structural integrity were also discovered during the site survey. Based on the preliminary survey, although a truss system was installed to provide support for the billboard structure placed on the roof deck of the building, no evidence is seen on the improvement of the structural elements of this building to carry the additional load. Roof alterations were also observed in some structures to accommodate the installation of a water supply tank. Other structural integrity issues found in some buildings are the conversion of entire floors as storage spaces and also the installation of mezzanines for additional storage. These building use alterations have caused excessive sagging of the floor due to excessive weight brought about by stored supplies.

Some structural issues were brought about, not by modification of the structure, but by its original design. These are plan irregularity, vertical irregularity, mass irregularity, and pounding (Sevieri et al., 2019). Out of 25 structures, 36% require an in-depth structural investigation, as its condition is deemed poor based on the preliminary survey.

Many of the structures also have exhibited cracks. Fourteen (14) cultural heritage structures included in this research have shown visible cracks that range from mild to severe. Some cracks are so severe that it has already led to partial spalling and exposure of some portion of the reinforcing steel which resulted in corrosion of steel bars. A building that seemed to have cut off some of the structural elements (i.e. columns) to provide more commercial space, also has its external columns exhibiting severe wide and lengthy cracks.

7. Conclusion

Using the seismic risk assessment tool, five (5) out of twenty-three (23) CH structures in Calle Real turned out to have a high-risk seismicity rating while the rest of the structures have a medium risk rating. The year built, pounding, and building height, are the vulnerability factors that are commonly found in most of the structures (>20 structures). Cracks on walls, columns, and severe signs of deterioration of the finishing are the most common building condition modifiers, with at least half of the structures manifesting these conditions. Along with hazard rating, these vulnerability factors and building code modifiers were used to assess the seismic risk indices of CH structures in Calle Real.

The seismic risk assessment was conducted with a preliminary site survey. This preliminary site survey has identified functional and structural issues in the CH structures in Calle Real. Some of the issues were a direct result of adaptive reuse since commercial tenants of the structures had made some alterations in the structure to either add commercial space or add storage spaces. An indirect result of adaptive reuse had to do with the structure being old and had survived several calamities already like typhoons and earthquakes. These indirect results were manifested through cracks on walls, columns, and beams of the structures.

The result of this study fairly indicates that the use of cultural heritage structures through adaptive reuse must need an in-depth structural investigation to ensure the reliability and safety of the structures.

Acknowledgments

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