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Rapid visual screening and seismic vulnerability assessment of Queensland's vintage unreinforced masonry buildings

Hossein Derakhshan[1], Nouman Khattak[1], Jane Sexton[2], Mark Edwards[3], and Martin Wehner[3], and David Thambiratnam[1]

1. Queensland University of Technology, 2 George Street, Brisbane, QLD 4000

2. Queensland Fire and Emergency Services

3. Geoscience Australia

Abstract

Many past earthquakes have highlighted the seismic risk posed by the vintage stock of unreinforced masonry (URM) buildings to communities around the world. Low seismicity areas such as Australia have not been an exception, with the Newcastle 1989 earthquake among others demonstrating the vulnerability of such buildings. It has also been found that the most recurring types of URM building seismic damage are the ones created through local mechanisms forming within the building. These failures include the out-of-plane collapse of walls and parapets and toppling of chimneys and other appendages. These parts of the buildings are often collectively called nonstructural URM components. In a research campaign supported by the Queensland Fire and Emergency Services (QFES), foot surveys were conducted in 12 towns and cities across Queensland to ascertain the types and distribution of nonstructural URM components in 1111 identified buildings. In addition, many other externally visible details were documented. The activities included creating a Rapid Visual Screening (RVS) checklist to assist with the surveying. The collected data on the buildings were interpreted and subdivided into different typologies and seismic vulnerability categories utilizing both the earlier works by Geoscience Australia and the University of Adelaide in York, WA and other international research. The relative seismic vulnerability of the buildings was calculated based on an international method which was modified to suit Australian building typologies. The outcomes of the research enable the emergency management sector including QFES to improve risk management strategies before and after a potential seismic event. An overview of the research activities including a summary of building statistics and the calculated relative seismic vulnerability distributions is presented in this paper.

Keywords: URM building, rapid visual screening, survey, local mechanism, nonstructural component, seismic vulnerability.

1 Introduction

Australia has a significant stock of pre-WWII masonry buildings, which have been designed only for gravity and wind loading. Several relevant Australian URM building typology studies include Howlader et al. (2016), Griffith et al. (2017), and Vaculik et al. (2018), and Wehner (2020). These studies, that excluded Queensland, highlighted some similarities between the URM construction in the different states but also some major differences. The documented differences such as the type of material (stone vs brick), wall configuration (cavity, solid), typology prevalence, etc suggested that state-specific studies must be conducted to accurately determine building exposure.

Despite their prevalence, an accurate inventory of Queensland URM buildings has remained a research gap. Given this shortcoming, Queensland Fire and Emergency Services (QFES) engaged QUT researchers to collect URM building exposure data in different Queensland localities. In addition, the project had a scope to provide statistics and distribution of some of the building parameters that affect their seismic vulnerability.

As part of the project a Rapid Visual Screening (RVS) checklist was prepared in consultation with Geoscience Australia (GA). Foot surveys were conducted to complete the checklists, and this activity was followed by desktop studies to interpret the data.

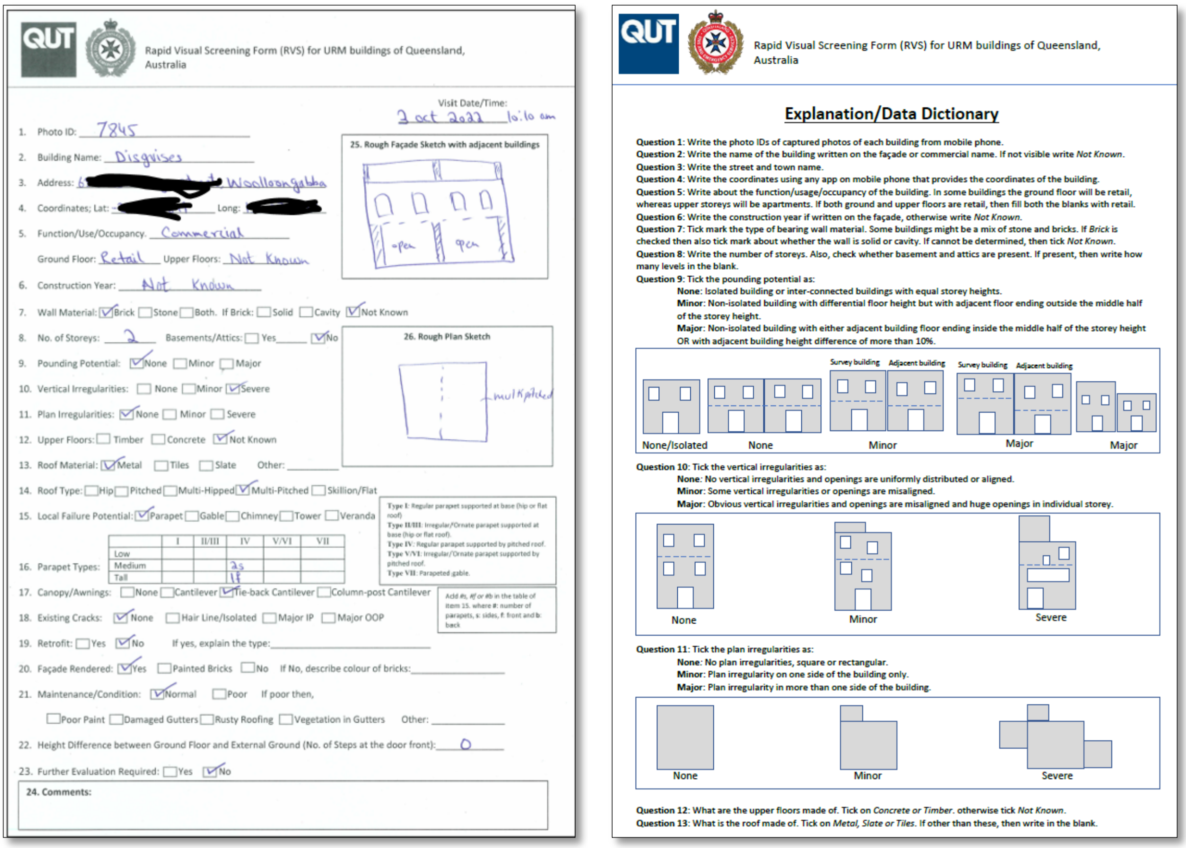
The scope of the study covered 12 towns and cities including Brisbane and many of the densely populated towns. Most of these towns are located within the region of highest earthquake risk for Queensland (Zone 3), as defined in the Queensland State Earthquake Risk Assessment (2019).

This report includes a description of RVS checklist, the survey results, and the preliminary interpretations including building classification and an assessment of the buildings relative seismic vulnerability.

2 Rapid visual screening (RVS) checklist

A Rapid Visual Screening (RVS) checklist (Figure 1a) was prepared using information from 3 sources and updated as required. These sources were FEMA-154 (FEMA 2015) guidelines, Initial Evaluation Procedure (IEP) of New Zealand (IEP 2017), and Bushfire and Natural Hazards CRC Case study of York Shire (Project A9; Wehner 2020).

The checklist has 26 fields for each building, with explanatory examples and guidelines for completing the fields being provided in the form (Figure 1b). Of the 26 fields, 6 are administrative information such as the building locality coordinates, address, name, and photograph IDs. Fifteen fields relate to the immediately visible details such as the number of stories, wall material type, function of the building, presence of URM appendages such as parapets or chimneys, and roof type. A further 5 parameters require engineering judgement and/or simple calculations. These fields are pounding potential [9], vertical irregularity [10], plane irregularity [11], existing cracks [18], and maintenance conditions [21] and were assessed in a qualitative manner (e.g. None, Minor, Major).



Rapid Visual Screening Form (RVS) for URM buildings of Queensland, Australia

Visit Date/Time: 3 oct 2022 10:10 am

1. Photo ID: 7845
2. Building Name: Disguises
3. Address: [redacted] Woolloongabba
4. Coordinates; Lat: [redacted] Long: [redacted]
5. Function/Use/Occupancy. Commercial
   Ground Floor: Retail Upper Floors: Not Known
6. Construction Year: Not Known
7. Wall Material: ☑ Brick ☐ Stone ☐ Both. If Brick: ☐ Solid ☐ Cavity ☑ Not Known
8. No. of Storeys: 2 Basements/Attics: ☐ Yes____ ☑ No
9. Pounding Potential: ☑ None ☐ Minor ☐ Major
10. Vertical Irregularities: ☐ None ☐ Minor ☑ Severe
11. Plan Irregularities: ☑ None ☐ Minor ☐ Severe
12. Upper Floors: ☐ Timber ☐ Concrete ☑ Not Known
13. Roof Material: ☑ Metal ☐ Tiles ☐ Slate Other: ______
14. Roof Type: ☐ Hip ☐ Pitched ☐ Multi-Hipped ☑ Multi-Pitched ☐ Skillion/Flat
15. Local Failure Potential: ☑ Parapet ☐ Gable ☐ Chimney ☐ Tower ☐ Veranda
16. Parapet Types:

	I	II/III	IV	V/VI	VII
Low					
Medium			2s		
Tall			1f		

Type I: Regular parapet supported at base (hip or flat roof)
Type II/III: Irregular/Ornate parapet supported at base (hip or flat roof).
Type IV: Regular parapet supported by pitched roof.
Type V/VI: Irregular/Ornate parapet supported by pitched roof.
Type VII: Parapeted gable.

Add #s, #f or #b in the table of item 15. where #: number of parapets, s: sides, f: front and b: back

17. Canopy/Awnings: ☐ None ☐ Cantilever ☑ Tie-back Cantilever ☐ Column-post Cantilever
18. Existing Cracks: ☑ None ☐ Hair Line/Isolated ☐ Major IP ☐ Major OOP
19. Retrofit: ☐ Yes ☑ No If yes, explain the type: ______
20. Façade Rendered: ☑ Yes ☐ Painted Bricks ☐ No If No, describe colour of bricks: ______
21. Maintenance/Condition: ☑ Normal ☐ Poor If poor then,
    ☐ Poor Paint ☐ Damaged Gutters ☐ Rusty Roofing ☐ Vegetation in Gutters Other: ______
22. Height Difference between Ground Floor and External Ground (No. of Steps at the door front): 0
23. Further Evaluation Required: ☐ Yes ☑ No

24. Comments:

25. Rough Façade Sketch with adjacent buildings

26. Rough Plan Sketch

1a. Example of completed checklist

Rapid Visual Screening Form (RVS) for URM buildings of Queensland, Australia

Explanation/Data Dictionary

Question 1: Write the photo IDs of captured photos of each building from mobile phone.
Question 2: Write the name of the building written on the façade or commercial name. If not visible write *Not Known*.
Question 3: Write the street and town name.
Question 4: Write the coordinates using any app on mobile phone that provides the coordinates of the building.
Question 5: Write about the function/usage/occupancy of the building. In some buildings the ground floor will be retail, whereas upper storeys will be apartments. If both ground and upper floors are retail, then fill both the blanks with retail.
Question 6: Write the construction year if written on the façade, otherwise write *Not Known*.
Question 7: Tick mark the type of bearing wall material. Some buildings might be a mix of stone and bricks. If *Brick* is checked then also tick mark about whether the wall is solid or cavity. If cannot be determined, then tick *Not Known*.
Question 8: Write the number of storeys. Also, check whether basement and attics are present. If present, then write how many levels in the blank.
Question 9: Tick the pounding potential as:
  None: Isolated building or inter-connected buildings with equal storey heights.
  Minor: Non-isolated building with differential floor height but with adjacent floor ending outside the middle half of the storey height.
  Major: Non-isolated building with either adjacent building floor ending inside the middle half of the storey height OR with adjacent building height difference of more than 10%.

Question 10: Tick the vertical irregularities as:
  None: No vertical irregularities and openings are uniformly distributed or aligned.
  Minor: Some vertical irregularities or openings are misaligned.
  Major: Obvious vertical irregularities and openings are misaligned and huge openings in individual storey.

Question 11: Tick the plan irregularities as:
  None: No plan irregularities, square or rectangular.
  Minor: Plan irregularity on one side of the building only.
  Major: Plan irregularity in more than one side of the building.

Question 12: What are the upper floors made of. Tick on *Concrete or Timber*. otherwise tick *Not Known*.
Question 13: What is the roof made of. Tick on *Metal, Slate or Tiles*. If other than these, then write in the blank.

1b. A page from the checklist guide

Figure 1.RVS checklist

3 Surveys

In the early stages of the project, historical statistical reports (e.g. MSHT 1921) were used to identify the localities with the highest probable distribution of pre-WWII URM buildings. These localities were amended as required by stakeholders to include some towns with cultural and heritage importance such as Charters Towers and Childers. The final 12 surveyed towns are marked in Figure 2a.

3.1 Methods and Tools

The surveys were conducted on foot, and in many towns by a single researcher. On a limited number of days, larger teams of up to 4 student researchers participated in data collection. As part of the surveys a Factsheet (Figure 2b) that described the project purpose was distributed on demand to interested building owners.

As many of the masonry buildings are constructed using modern materials and techniques, criteria were developed that assisted with identification of vintage (pre-WWII) buildings. These checks included observing the building for unique architectural details such as raised parapet, arched windows, and distinctive ornamental masonry features.

Wherever possible aerial view of the buildings were checked on the Internet to ascertain roof types or plan of the buildings. In many cases, several checklist fields were left empty and completed later by accessing online tools in a desktop computer (Metromap https://metromap.com.au/; Nearmap https://www.nearmap.com/au/en, Google Map). In addition, online heritage registers such as Queensland Heritage Register (https://apps.des.qld.gov.au/heritage-register/) and Brisbane Local Heritage Register (https://heritage.brisbane.qld.gov.au/) were used (see for example Nouman et al. 2023 for Brisbane) to complete some of the missing information like the year of construction. It is highlighted that while all QHR-listed masonry buildings were identified prior to surveys and then surveyed, the opposite is not true, i.e. not all surveyed buildings were found to be present in the QHR register. In summary, 588 of the 1111 buildings were QHR-registered.

2a. Locality of the surveyed towns

Unreinforced Masonry Building Seismic Vulnerability Assessment for Queensland

The Project

The Unreinforced Masonry (URM) Building Seismic Vulnerability Assessment for Queensland (QLD) is a collaborative project between Queensland University of Technology (QUT) and Queensland Fire and Emergency Services (QFES). The project is aimed at providing information on the prevalent typologies of vintage URM buildings in QLD and the associated seismic vulnerability. The project started 1 September 2022 and is due for completion by 30 June 2023.

Why URM buildings?

Queensland has many older masonry buildings (see Figure 1; Top), which predate the development of modern building design codes. These buildings were generally designed for gravity and wind loads and are inherently vulnerable to low to moderate earthquakes as demonstrated during the 1989 Newcastle earthquake (Magnitude ML 5.6; see Figure 1; Bottom). Low to moderate earthquakes frequently occur in QLD, with the recent examples including the 2011 and 2016 earthquakes offshore Bowen (Magnitudes ML 5.3 and 5.8), the 2015 Fraser Island earthquakes (Magnitude ML 5.6), and the 2015 Eidsvold earthquake (Magnitude ML 5.2). Knowledge of the prevalent types of URM buildings encountered in QLD will enable QFES to work with local governments to inform risk management strategies by simultaneously considering earthquake and all other hazard types.

What will Queensland residents notice?

From September 2022 to June 2023, a 3-member team from QUT will gather information on the older masonry buildings in selected QLD cities and towns. Information such as construction type, building materials, building height and the presence of features such as chimneys and parapets will be recorded on a form called Rapid Visual Screening (RVS). In addition, a few photographs will be taken from the building exterior. The survey takes about 10 minutes, and the team may also ask permission to briefly view the interior of some buildings. Participation in this interior inspection is voluntary.

What about privacy and confidentiality?

The collected information will be used for emergency planning only. If publication from this research is planned, it will exclude the building names and other immediately identifiable attributes.

Figure 1: Top: Typical URM buildings in QLD towns; Bottom: Damage to URM building in 1989 Newcastle earthquake (Photo by Craig Smith).

For Further Information:

1. Dr. Hossein Derakhshan, QUT, Email: Hossein.derakhshan@qut.edu.au
2. Hazard and Risk Unit, QFES, Email: hazard.risk@qfes.qld.gov.au

@QUTBrisbane @qutrealworld @QUT @TheQUTube @qutrealworld

2b. Project Factsheet

Figure 2. Survey map and Factsheet

3.2 General statistics

In total, 1111 buildings were surveyed, with the building distribution being detailed in Table 1.

Table1. Number of surveyed buildings

Location	# of bldg
Brisbane CBD	180
Brisbane Suburbs: Fortitude Valley Woolloongabba West End other suburbs within 5 km radius combined	Total: 192 112 45 12 23
Ipswich	78
Toowoomba	110
Rockhampton	109
Maryborough	95
Townsville	75
Bundaberg	67
Gympie	64
Warwick	60
Charters Towers	46

Gladstone	19
Childers	16
Total	1111

3.3 Building typologies

Most of the buildings were classified into typologies that were consistent with Wehner et al. (2020), who classified URM buildings typical of WA Wheatbelt towns, into the following 10 typologies.

- URM 1: Single storey residential houses
- URM 2: 2-storey pubs
- URM 3: 1-storey row buildings
- URM 4: 2-storey commercial buildings
- URM 5: 2-storey post office buildings
- URM 6: 2-storey bank building
- URM 7: 3-5 storeys commercial
- URM 8: 6+ storey buildings
- URM 9: Church
- URM 10: 2-storey town halls

It was found that about 10% of the surveyed buildings had a typology different from that identified for the WA Wheatbelt towns. For example, these types included “school buildings” and “two-storey residential buildings”, “hotels” that were not necessarily a Pub (Type 2) or were more than 2-storey, “masonic centre”, "Court House", "police station", “fire station”, and “state library”. These new types of the buildings were categorically marked as “others” in this study:

- Others: Buildings not categorised elsewhere

As detailed in Table 2, 2-storey commercial building (URM4) was the overall most prevalent building type followed by single-storey row buildings (URM3). However, there was some variations in building popularity across different localities, for example 3-5 storey commercial buildings (URM7) were the most prevalent type in Brisbane CBD. These buildings form the character of the CBD and are distributed almost evenly across the city (Figure 3).

Table2. Building typology

Towns	**URM Typology Class**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Others**	**Total**
Brisbane region												
CBD	0	5	5	42	0	1	81	13	11	4	18	180
Fortitude Valley	0	15	18	52	1	0	19	1	4	0	2	112
Woolloongabba	0	4	6	26	1	0	1	0	3	0	4	45
West End	0	1	3	5	0	0	1	0	1	0	1	12
Brisbane Other Suburbs	0	2	3	11	0	0	2	0	1	0	4	23
Localities outside Brisbane region												
Toowoomba	1	8	15	55	1	3	10	0	7	1	9	110
Rockhampton	0	6	29	44	1	3	6	0	4	1	15	109
Maryborough	0	8	25	43	1	2	2	0	6	1	7	95
Ipswich	0	0	18	37	1	1	1	0	5	1	14	78
Townsville	0	10	10	24	1	4	9	0	3	2	12	75
Bundaberg	1	6	21	25	1	2	0	0	4	0	7	67
Gympie	0	5	24	24	0	2	0	0	2	2	5	64
Warwick	2	2	21	19	0	3	0	0	3	1	9	60
Charters Towers	0	3	26	5	1	4	0	0	1	-	6	46

Gladstone	0	1	9	3	0	2	0	0	0	1	3	19
Childers	0	2	10	2	0	0	0	0	0	0	2	16
Total	**4**	**78**	**243**	**417**	**9**	**27**	**132**	**14**	**55**	**14**	**118**	**--**
											Grand Total	**1111**

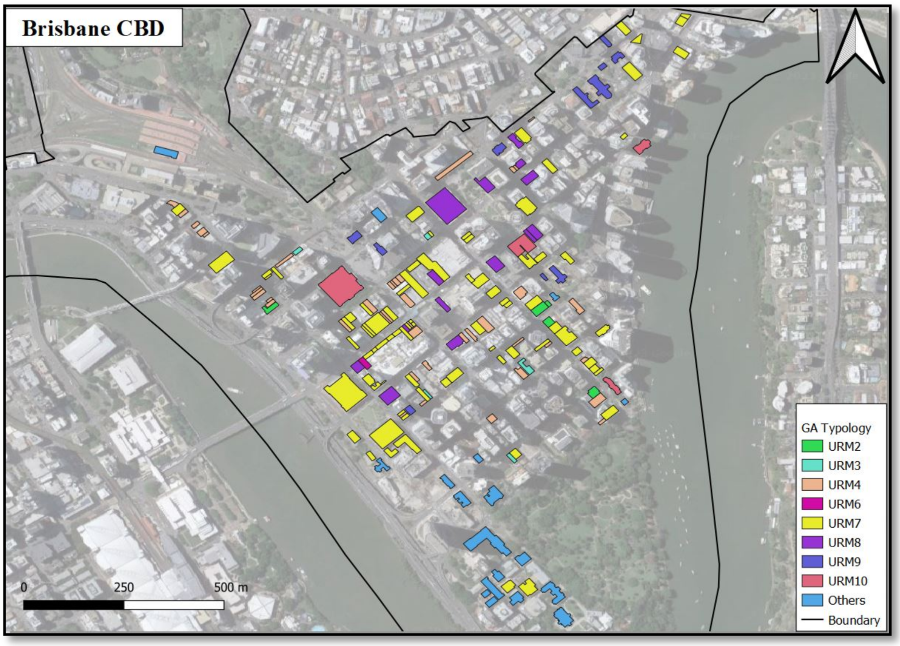


Figure 3. Geospatial distribution of pre-WWII URM buildings in Brisbane CBD

3.4 Other statistics

Several other significant statistics are presented in Table 3 by grouping the parameters into 5 seismic vulnerability classes (A to E). For the first 5 parameters listed in Table 3, factual information was used to determine the vulnerability parameter Parapet height was estimated (not measured) by using clues such as the number of brick courses. The next 5 parameters were assigned a vulnerability class based on the engineering judgment of the surveyor.

Table3. Building typology

Description	Vulnerability Class				
	A	B	C	D	E
# of Storeys [8]	0	1	2	3	4+
Parapets, Chimney, towers [15]	None				If any one present
Attachments [17]	None		Light, column-post canopies		Cantilever or tie-back canopies, balconies, finials
Parapet Height [16]	None		Shorter than 500 mm		Taller than 500 mm
Parapet support [16]			Supported at the base		Sloped Support
Qualitative assessment					
Pounding [9]	None		Minor		Major
Vertical Irreg. [10]	None		Minor		Major
Plan Irreg. [11]	None		Minor OR Wide shopfront openings		Major
Cracks [18]	None		Hairline or Minor		Major

Maintenance [21]	Normal				Poor

Figure 4 shows that almost all the surveyed buildings had one of either Parapet, Chimney, Tower, or a Gable End, and hence a vulnerability class of E was assigned to them. Similarly, over 65% of the buildings had vulnerability class E for parapet height, with this class meaning that a parapet with the height of greater than 500 mm was found in the buildings.

More than 50% of the buildings had a Heavy attachment such as tie-back or cantilever canopy (see also Table 3). More than 40% of the buildings was found in a Poor maintenance condition. About 50% of the buildings were found to have cracks ranging from minor to major.

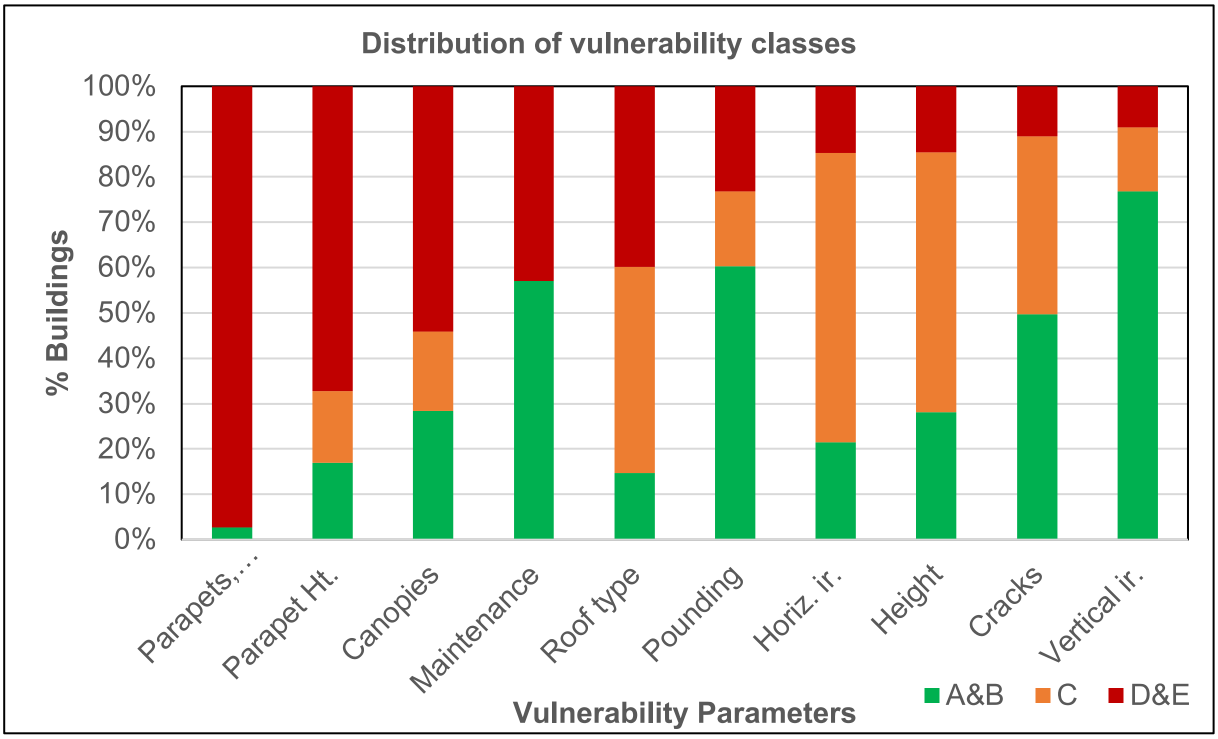


Figure 4. Distribution of vulnerability classes among 10 significant parameters of the buildings

4 Assessment of relative seismic vulnerability

Individual building vulnerability index (VI) for European URM building typologies has been proposed by Vicente (2008) and modified by Ferreira et al. (2014). The index can be used for ranking of the buildings according to their relative seismic vulnerability. Finding the index involves calculating the weighted sum of vulnerability scores (C_i) assigned to a few behaviour-influencing building aspects which are typically inspected using external surveys. The scoring system follows the assignment of vulnerability classes to parameters such as that detailed in Table 3. The scoring system that was used in this research is detailed in Table 4, which shows that a score of either 0, 5, 15, 20, or 50 is attributed to each of the vulnerability classes of A, B, C, D, and E. Each parameter has a weighing contribution (P_i) to the final vulnerability index, which can be calculated using Equation (1).

The parameters described in Table 3 (repeated in Table 4) closely match those proposed in the original study (Vicente 2008). However, there are some differences, with the reason being that the original method included aspects or building features not commonly seen in Australian buildings (e.g. cross ties) or lacked details sufficient to represent Australian URM typologies. In the current study, some original parameters were replaced with others that were deemed to have the same effects on the building response. The weighting ratios were kept as close as possible to the original method. However, it is highlighted that this relative vulnerability assessment method requires validation.

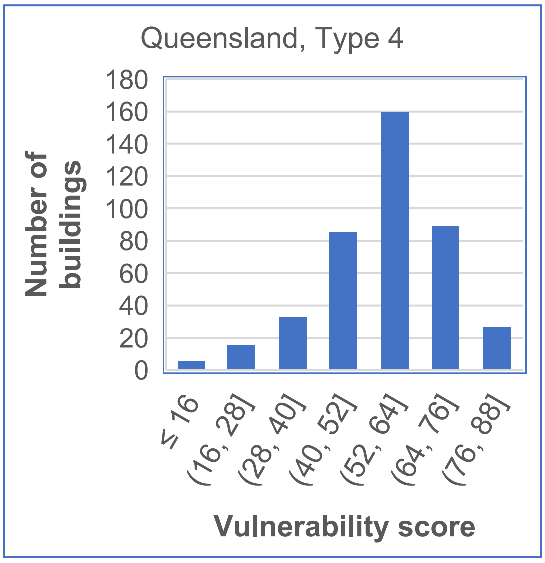
Table 4. Vulnerability scores and weighing

Parameters	Description	Class, C_i					Weight P_i
		A	B	C	D	E	
P1	Number of storeys	0	5	15	20	50	1
P2	Cracks in façades	0	-	15	-	50	1
P3	Pounding potential	0	-	15	-	50	0.5
P4	Vertical Irregularities	0	-	15	-	50	0.5
P5	Plan Irregularities	0	-	15	-	50	0.25
P6	Presence of parapets, chimneys, towers, gables, cornice	0	-	-	-	50	1
P7	Maintenance	0	-	-	-	50	1
P8	Elements connected to the façade	0	-	15	-	50	0.25
P9	Parapet height	0	-	15	-	50	2
P10	Roof support	0	-	15	-	50	1

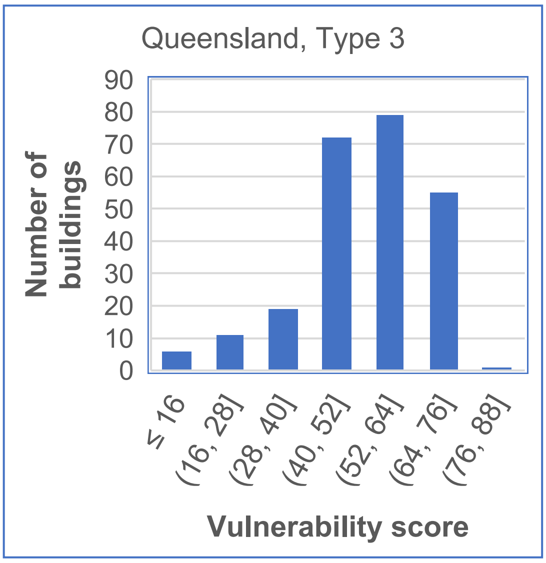
$$\boldsymbol{VI} = \sum_{i=1}^{10} \boldsymbol{C_i\, P_i} \tag{1}$$

A vulnerability index (VI) value ranging from 0 to 425 can be obtained from Equation (1). For ease of use, the vulnerability index (VI) was normalised to range between 0 and 100 ((sum (Ci*Pi)) *100/425); the higher its value, the higher the seismic vulnerability of the building.

Histogram plots of normalised VI suggests such as those shown for the two most prevalent building types suggest some differences in the relative vulnerability. Two-storey commercial buildings (Figure 5a) show a peak in the VI in the (52-64] bracket, while for the single-storey row buildings the peak at this bracket is not as emphasised. Both plots suggest that there are only a few buildings within the extreme VI bracket (VI>74%), with these buildings could be selected for more detailed studies.



5a. Building class URM4



5a. Building class URM3

Figure 5. Distribution of normalised vulnerability index for the two most prevalent building types

As a final step of this project, the geospatial distribution of the normalised VI calculated for all the surveyed buildings was incorporated into QGIS file format (e.g. Figure 6), with the data having potential to assist authorities with their risk management strategies.

Figure 6. Geospatial distribution of VI in Brisbane

5 Conclusions

A typological characterisation of pre-WWII buildings in QLD was conducted through foot surveys. For each building a checklist was completed that documented significant building details that can be determined through an external observation.

It was found that building typologies were similar to those described in an earlier research project which focussed on the town of York, WA although about 10% of the buildings had a type not found in the earlier study. The 2 most prevalent building types were 2-storey commercial and single-storey row buildings, which combined represented about 60% of the total 1111 buildings.

It was found that building maintenance is a significant issue with more than 40% of URM buildings being in a poorly maintained condition. It was also found that about 50% of the buildings had existing cracks which ranged from minor (40%) to major (10%) cracks. Heavy attachments such as tie-back or cantilever canopies were present in more than 50% of the buildings. Almost all the buildings had either a parapet, chimney, tower, or a gable end. More specifically, about two-third of the buildings were found to have parapets that were higher than 500 mm.

A challenge was highlighted in utilising URM vulnerability assessment methods developed overseas for application to Australian buildings with one method being altered to suit the specifics of Australian buildings. The method requires further validation before it can be used as a viable risk assessment tool. Another challenge in the way of reliable risk assessments is the material properties of the buildings, which require in-situ data collection.

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