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Inventory method for urban seismic risk studies

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Abstract: The first step in seismic risk assessment studies consists of collecting the inventory of the exposed assets. The distribution of the building types combined with respective fragility curves and assumed seismic scenario generates results for the damage estimates. Building specific parameters used in urban seismic risk studies are traditionally collected by sidewalk surveys relying mainly on the global visual characteristics. This approach is, however, time consuming and the reliability of the assigned structural type is highly dependent on the surveyor expertise. A methodological approach for rapid building inventory is proposed with the objective to increase efficiency and reduce subjectivity in data collection. It is based on analyses of the information given in municipal property databases. The statistical analyses of the municipal data were combined with a study of the evolution of typical construction systems in Québec City, selected as a study area, and the Province of Québec in general. Correlations were established between the municipal data and building types proposed in Hazus loss estimation methodology to build an inference matrix indicating the most probable structural type to be assigned to a building. The developed inventory methodology was applied over two samples of buildings, 207 and more than 2,000 buildings in downtown Québec City, to validate the assumptions of the inference matrix. The calibrated procedure was then applied to the whole set of 16,421 buildings. As an example of application, the conducted inventory was used for the seismic risk assessment study of the 1,220 buildings in Old Québec City.

1 Introduction

This study is part of the ongoing collaboration on the Quantitative Risk Assessment project between the Geological Survey of Canada, Natural Resources Canada, and the École de technologie supérieure - ETS, Montréal, with the objective to adapt the well known multi-hazard loss estimation tool Hazus (FEMA-NIBS 2003) to the Canadian context. The part of the project carried out by the ETS includes four steps: (i) development of a methodological approach to perform specific building inventory using municipal databases (Nollet et al. 2012), (ii) structural characterisation and vulnerability analysis of Vieux-Québec stone masonry buildings, a structural typology not explicitly considered in Hazus (Abo El Ezz et al. 2011a Abo El Ezz et al. 2013), (iii) development of rapid method for urban seismic risk evaluation (Abo El Ezz et al. 2011b), and (iv) validation of the method through a seismic risk evaluation of existing buildings in Québec City for different earthquake scenarios (Abo El Ezz 2013).

In Hazus, the building inventory data is grouped into two categories: occupancy and structural type (FEMA-NIBS 2003). Occupancies define the building count, square footage, building exposure value and content exposure value. Seven general occupancy categories are considered: residential, commercial, industrial, agricultural, religious/non-profit, governmental, and educational buildings. These are further subdivided into 28 specific occupancy classes. From the structural point of view there are 36 major building structural types depending of the construction material (wood, steel, concrete, masonry and manufactured housing), lateral force resisting system (bearing wall, shear wall, frame, etc.), and building height (low: 1-3 stories, medium: 4-7 stories, and high-rise: 8+ stories). The apparent resistance to seismic loads for each building class is assigned with one of the four available design criteria (pre-code, low-code, moderate-code, and high-code), mainly functions of the year of construction. Note that each of the assumed building classes is not representative of a specific building but rather of a population of buildings with similar structural properties.

This paper presents the methodological approach to perform specific building inventory based on the building types assumed by Hazus and in view of detailed urban seismic risk studies. The method was developed in the specific context of the existing building stock in Québec City. In a site specific inventory, building class (structural type) is assigned to each building or a group of buildings according to their main structural characteristics such as construction material and lateral force resisting system (LFRS). Structural type and other important building parameters are generally collected by traditional sidewalk survey methods considering the global visual building characteristics. Depending on the size of the study area, this approach may be extremely time consuming, costly, difficult to update and the reliability of the assigned structural type is highly dependent on the surveyor's expertise. The methodological approach for rapid building inventory presented in this document is proposed with the objective to increase efficiency and reduce subjectivity in data collection. The resulting building inventory of downtown Québec City (16,421 buildings) is an example of midsize urban centers in Eastern Canada. The developed method was applied for seismic risk assessment for 1,220 buildings in historical Old Québec City sector for scenario event of magnitude 6.2 at distance 15 km (M6.2R15) using the risk assessment methodology developed by Abo El Ezz (2013).

2 General methodology

A detailed building inventory collected with the objective to perform a seismic risk study with the Hazus methodology comprises a designation of two major parameters to each of the existing buildings in the study area: occupation and structural type (building class). Essentially, these parameters are assigned based on: actual use of the building, construction material, year of construction, number of stories, etc. Probably the most difficult information to obtain for a given building is its structural type. Traditionally for large inventories, walking survey is generally carried out to assign the structural type and confirm basic information from municipal database (year of construction, number of stories and occupation). However, visual inventory are long and costly and lead to large margins of error since reliability of the assigned structural type is highly dependent on the surveyor's expertise, especially when engineering drawings are not available (Ploeger et al. 2009; Ploeger 2008; Yu 2011). An alternative approach is to collect the necessary inventory information directly from an existing database, such as municipal property database. This approach relies on the definition of inference correlations between available and required data in view of deducing the most probable building structural type (French 1991). The inventory method proposed in this study was developed according to this second approach and included the following three main steps:

- Step 1: Statistical analysis of basic information present in the municipal property database (year of construction, number of stories, building use, and floor area).
- Step 2: Development of logic correlations to assign structural type based on the results of Step 1 and the analysis of the evolution of the typical construction systems for residential, industrial, commercial and institutional occupancy classes.
- Step 3: Inventory of the existing buildings in the district of La Cité-Limoilou (16,421 buildings) carried out using the inference matrix developed in Step 2.

The inventory methodology is validated by comparing the results from the proposed inference matrix with the inventory from a walking survey of 207 buildings as well as confirmation of construction material from documentation.

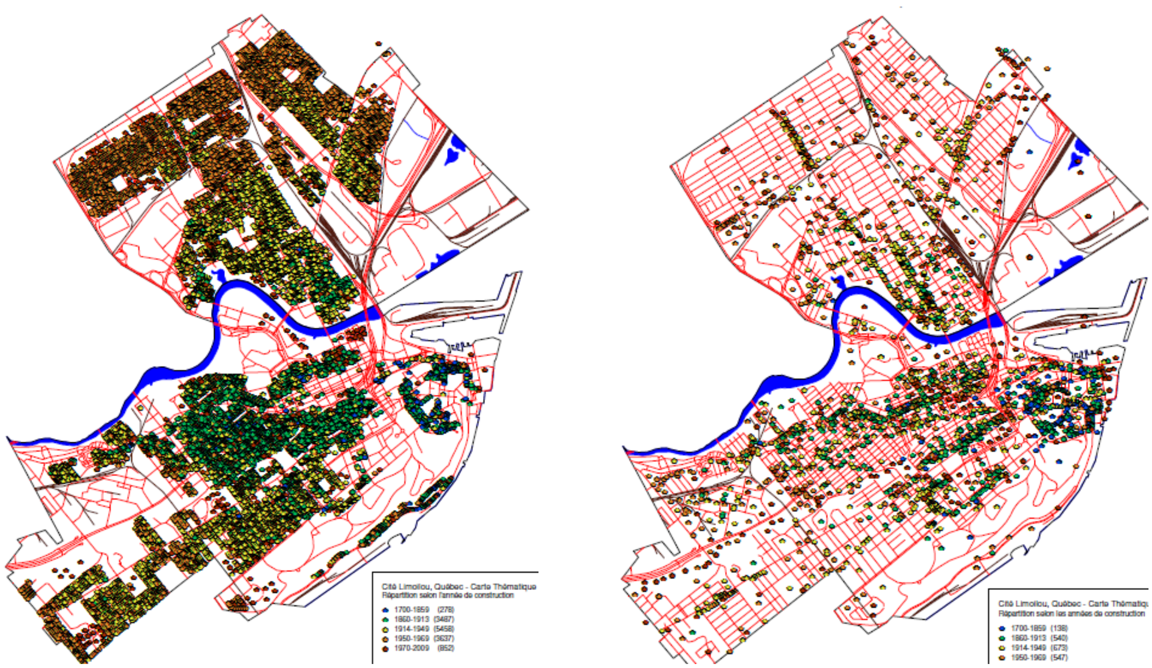
3 Statistical analysis of basic information

The City of Québec with population of approximately 500,000, occupies an area of 468 km^2, and comprises six districts: La Haute-Saint-Charles, Charlesbourg, Beauport, Sainte-Foy-Sillery-Cap-Rouge, Les Rivières and La Cité-Limoilou. This study focuses on La Cité-Limoilou district with a population of 108,000 and an area of 22 km[1]. The municipal property database provided by the Service d'évaluation de la Ville de Québec includes information on 23,266 civic addresses, corresponding to 16,421 physical buildings. The data initially extracted from the municipal property database consisted of: year of construction, number of stories, number of apartments or businesses in a single building, geographical coordinates, apartment floor area, building use (actual use, e.g. parking lot, and designated use. e.g. commercial). This information had to be converted into physical buildings with proper occupancy and structural type.

The first step to data analysis was to confirm the acquired building information. This was done by:

- using Québec City interactive map for aerial view and municipal zoning information.
- using Google Map® and Street View® web applications to visualize screened buildings from their geographical coordinates and addresses.
- walking survey of limited extent to confirm doubtful information on number of stories and number of physical building associated to several civic addresses.

Analysis of the existing 16,421 buildings information in the municipal property database for La Cité-Limoilou was first performed. Approximately 86% of the occupancy is residential, 11% is commercial, while more than half of the remaining buildings (1.6%) is designated as governmental or institutional. Figures 1 illustrate the distribution of residential buildings and all other remaining occupational categories.



(a) Residential buildings (b) Commercial, industrial, government and institutional buildings

Figure 1 **:** Distribution of building occupancy in La Cité-Limoilou district.

A detailed analysis was then carried out to correlate information between occupancy, year of construction, geographical location, and number of stories. Intensive construction period is observed between 1900 and 1949 for residential, commercial and government buildings, while the majority of

[1] http://www.ville.quebec.qc.ca/en/apropos/portrait/quelques_chiffres/index.aspx

schools were built between 1950 and 1969. The large majority of buildings (95%) have less than three stories, among which most are of 2-3 stories build between 1900 and 1949, whereas industrial and residential 1-2 stories buildings dominate the newer constructions after 1950. The majority of 4-7 stories are commercial buildings build between 1900 and 1950 (44%), while 8 stories and higher (35%) were constructed between 1970 and 1984.

Because of their predominant number, focus was given to the 14,335 residential buildings. Figure 2 illustrates the relation between the year of construction and the number of stories for residential buildings. Approximately 97% of residential buildings have 3 stories or less, while 68% were built before 1950, prior to the introduction of the first seismic provision in building codes. This represents 69% of the 1-2-3-stories buildings, 54% of the 4-7 storeys and 6% of the buildings higher than 8-stories. Half of the residential buildings with more than 8 stories were built between 1970 and 1984.

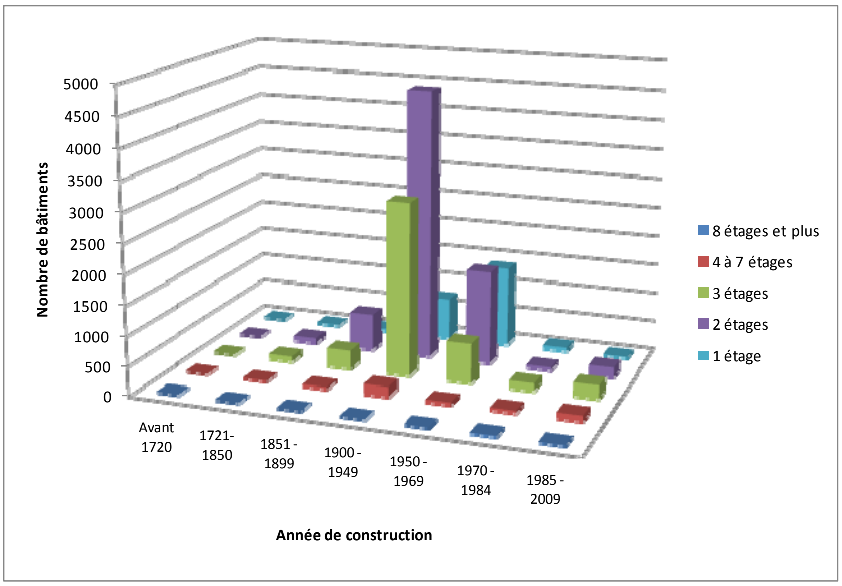


Figure 2 **:** Distribution of residential buidlings in La Cité-Limoilou district according to year of construction and number of stories.

This information will be used to define inference rules between year of construction, occupational use, number of stories and probable structural type. Table 1 presents the final distribution of buildings between Hazus occupancy classes for the seven sectors of La Cité-Limoilou. It should be noted that correspondence between actual use, as defined in the database and Hazus occupational class, had first to be established. For example, retirement homes are classified with commercial buildings in the city database but are defined as residential (RES6) in Hazus.

Table 1: Distribution of buildings in Hazus occupancy classes

	Limoilou	Vieux-Québec	St-Roch	St-Jean-Baptiste	St-Sauveur	Montcalm	St-Sacrement	Total
RES	6,396	765	734	1,014	2,866	1,356	1,214	14,345
COM	507	425	237	135	290	114	69	1,777
IND	61	3	12	8	56	2	0	142
REL	20	15	4	3	9	6	4	61
GOV	4	16	1	1	3	2	0	27
EDU	21	7	10	7	9	4	7	65
AUTRE	2	1	0	0	0	0	1	4
TOTAL	**7,011**	**1,232**	**998**	**1,168**	**3,233**	**1,484**	**1,295**	**16,421**

4 Evolution of typical construction systems

Standard seismic risk evaluation tools use sets of fragility functions defined for different structural buildings classes. A fragility function gives the probability of some undesirable event or physical damage (e.g., collapse) to take place as a function of a structure independent intensity measure (e.g. peak ground acceleration, spectral acceleration, etc.). For this study, the 36 building classes defined in Hazus were retained for the detailed inventory of the existing buildings. These 36 classes, described in details in the FEMA-155 manual (ATC 2002), are defined according to the construction material, e.g. wood, steel, concrete, stone masonry; structural lateral force resisting system (LFRS), e.g. frame or wall structure; and height, e.g. low-rise with 1 to 3 stories, mid-rise with 4 to 7 stories, and high-rise with +8 stories. The fragility data associated to each building class are modified to consider seismic design code level, e.g. pre-code for building not seismically designed, mid-code for buildings designed according to moderate seismic provisions and high-code level. Reference code buildings are based on modern code and years of reference vary according to seismic design zones. The year of construction is therefore one of the key data to perform urban seismic risk study.

The first step to assign structural type in a building inventory is to identify the construction material and the LFRS. To perform this task for the 16,421 building of the inventory, visual inspection and study of structural drawing was not considered as a realistic avenue. Also, as mentioned previously the reliability of the assigned structural type during the walking survey is highly dependent on the surveyor's expertise and the quality of the information: the structural elements and details being often not visible. It was therefore decided to first classify the existing buildings according to the construction material, e.g., masonry, wood, concrete or steel (Jaiswall and Wald 2008, French 1991). This information can be treated by geographical sector (census track), for which data on residential, commercial and industrial buildings are aggregated to obtain the proportion of each building class in a given census track.

To improve the level of confidence in the results, the evolution of typical construction systems in Québec City and the Province of Québec in general was studied. A timeline of the construction evolution was generated from review of architectural reports and theses, historic documents and archives (Bourque 1991; Vallières 1999; Lessard et Marquis 1972; Auger 1998; Laframboise et al. 1991) As an example, Figure 3 presents the timeline of the evolution of the construction systems of residential buildings in Québec City from the foundation of the city in 1640 to the beginning of the 20th century. The evolution of the construction systems for governmental, commercial, and industrial buildings was also studied (Nollet et al. 2012).

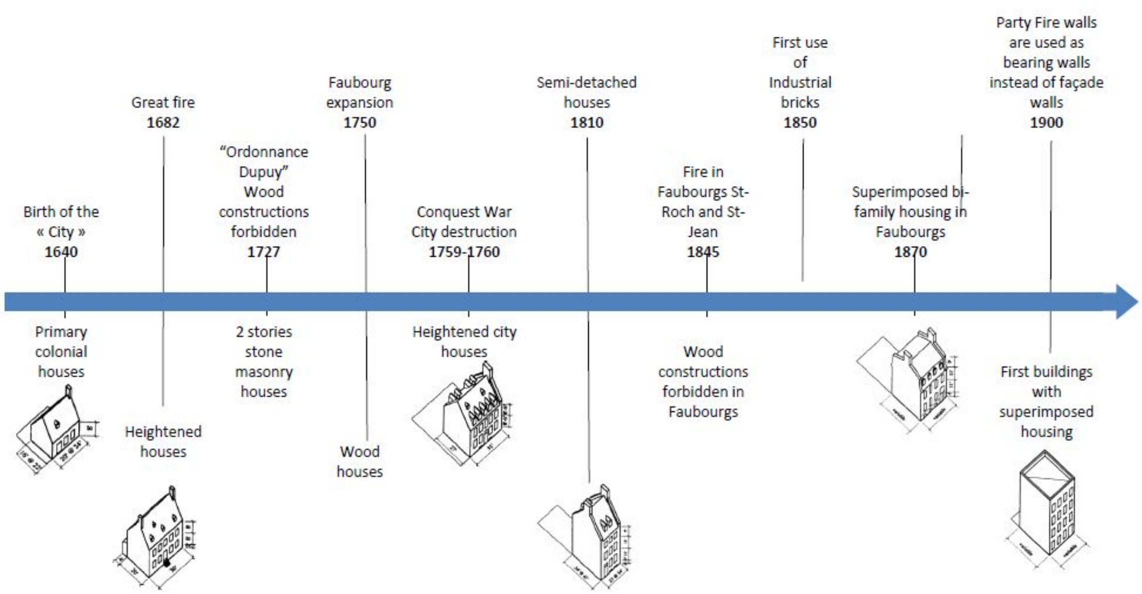


Figure 3 : Evolution of construction systems in Québec City.

The information on the evolution of the construction practice combined with the statistical analysis of the municipal property database were used to generate the inference relations between the most probable structural type (material and LFRS) and basic available data such as: year of construction, occupancy, number of stories and geographical location.

5 Inference matrix

A summary of the correlation between the approximate period of construction and the predominant occupancy category for each structural type was established based on the analysis of the evolution of the construction systems combined with the study of collected structural drawings and architectural documents. Table 2 illustrates the summary table for the district La Cité-Limoilou. It should be noted that a new unreinforced stone masonry (URM Stone) structural type was added to the standard Hazus structural types to cover this important category in the historic Old Québec City. A direct inference relation can be defined when only one potential structural type is identified for the combination of period of construction, number of stories and general occupancy. However, when several structural systems appear as potential candidates, as it can be seen in Table 2, inference relations are defined by a statistical approach for each probable structural type. Figure 4 illustrates a portion of the resulting inference matrix. Percentages were attributed using distribution of structural types by number of stories and Hazus occupancy category for Eastern United States (FEMA-NIBS 2003).

Table 2: Summary of the aproximate year of use for each structural type.

Structural types (ATC 2002)	Year	Number of stories	Use and number of stories (1 - 3, 4 - 7 , 8 +)																			
			Commercial			Industrial			Educational			Residential			Gouvernment			Religious		Hospital		
			1-3	4-7	8+	1-3	4-7	8+	1-3	4-7	8+	1-3	4-7	8+	1-3	4-7	8+	1-3	4+	1-3	4-7	8+
OLB / W1 (Downtown)	≥1900	≤4																				
OLB / W1 (Suburb)	All	≤4																				
PPB / W2	All	≤4																				
OAM / S1	≥1906-1980	1 à >8																				
OCA / S2	≥1930	1 à >8																				
OLA / S3	≥1950	1																				
AMB / S4	≥1920	1 à >8																				
AMR / S5	1890-1970	1 à >8																				
OBM / C1	1950-1972	1 à >8																				
MBC / C2	≥1950	1 à >8																				
BMR / C3	1950-1970	1 à 5																				
MBP / PC1	≥1950	1 à 2																				
OBP / PC2	≥1950	≤10																				
MAL / RM1	≥1930	≤10																				
MAB / RM2	≥1930	≤10																				
MNA / URM - Brick	1850-1950	1 à 6																				
New. Class: MNA / URM Stone	≤1850	1 à 6																				

Occupancy Class	Label	Height	Number of stories	Localisation	Construction year	Building type distribution
residential	RES1	Low-Rise	1-3	Downtown	Avant 1850	MNA PIERRE 100%
residential	RES1	Low-Rise	1-3	Downtown	1850-1900	MNA BRIQUE 100%
residential	RES1	Low-Rise	1-3	Downtown	1901-1949	MNA BRIQUE 95% + OLB 5%
residential	RES1	Low-Rise	1-3	Downtown	1950+	OLB 100%
residential	RES1	Low-Rise	1-3	Faubourg	Avant 1850	MNA PIERRE 20% + OLB 80%
residential	RES1	Low-Rise	1-3	Faubourg	1850-1940	MNA BRIQUE 20% + OLB 80%
residential	RES1	Low-Rise	1-3	Faubourg	1940+	OLB 100%
residential	RES3	Low-Rise	1-3	Downtown	Avant 1850	MNA PIERRE 100%
residential	RES3	Low-Rise	1-3	Downtown	1850-1900	MNA BRIQUE 100%
residential	RES3	Low-Rise	1-3	Downtown	1901-1949	MNA BRIQUE 95% + OLB 5%
residential	RES3	Low-Rise	1-3	Downtown	1950+	OLB 100%

Figure 4 **:** Example of the inference matrix for La Cité-Limoilou.

6 Validation of the methodology

Validation of the inference matrix was carried out in two steps. The first step consisted to validate the construction material by confronting the results given in the inference relations to the information available in the maps from the 'Atlas des assureurs' produced for insurance purposes (BANQ 1959). These maps are made available 50 years after their publication. Since as much as 67% of the existing buildings were built prior to 1950 (more than 60 years ago), this information was considered reliable. More than 2,000 buildings, or 13% of the inventory, were analysed and the maximum margin of error was around 5%. Construction material for some 600 of the buildings in the Old Québec City (Vieux-Québec-Cap-Blanc-Colline Parlementaire), representing 55% of the total number in this sector, was confirmed using drawings available in the archives of the Bibliothèque Nationale. The maximum margin of error was approximately 10%. This larger margin of error can be explained by the smaller size of the sample.

The second step consisted to perform a walking survey for 207 buildings in a part of the study area where occupancy and year of construction vary considerably. Figure 5 compares the distribution of buildings according to the construction material obtained during the walking survey with corresponding results obtained by applying the inference matrix. Out of the 207 surveyed buildings, 54% could be assigned a construction material simply from visual observation. For 28% of the buildings, the choice between two probable construction materials was uncertain, whereas for as much as 18% of the buildings the material of construction remained too difficult to ascertain. Among the 112 buildings for which the construction material was considered as certain, the assumption was validated against archive drawings. It appeared false 20% of the time.

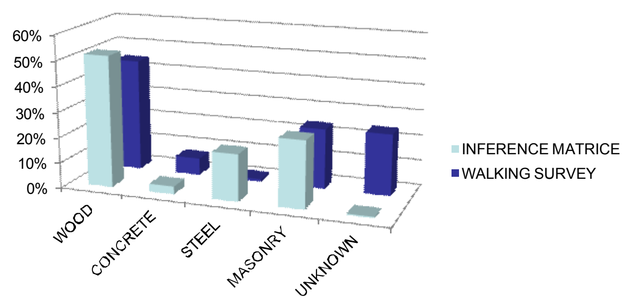


Figure 5 **:** Comparison of construction material inventory for 207 buidlings.

On the other hand, applying the developed inventory methodology using the inference matrix made it possible to assign a most probable construction type to the complete sample. Globally, this methodology seems more than satisfactory considering the high uncertainties related to walking survey inventory.

7 Application of the inventory methodology for a risk scenario study in Old Québec City

Table 3 gives the final building inventory of the existing 16,421 buildings in La Cité-Limoilou district according to structural types and occupancy classes as defined in Hazus (FEMA-NIBS 2003). It can be noted in Table 3 that 74% of the buildings are wooden structures, mostly ligth wooden structures (W1) predominant in low rise residential buildings. The proportion of unreinforced masonry brick structures (16% - URM Brick) is also significant. Only a smaller number of buildings (1.2%) are unreinforced stone masonry, a structural typology not explicitly considered in Hazus. Most of these buildings (168) are concentrated in the historical sector of Old Québec City where they represent 14% of the existing buildings (Figure 6).

Table 3: Building inventory for La Cité-Limoilou

		Wood		Concrete						Steel						Masonry				**	Total
		W1	W2	C1	C2	C3	PC1	PC2	*	S1	S2	S3	S4	S5	*	URM Stone	RM2	RM1	URM Brick		
Occupancy class	RES	11,860	0	11	8	2	6	7	218	13	27	0	5	10	49	102	4	2	2,009	13	14,345
	COM	265	17	26	34	0	51	10	0	185	255	0	12	190	1	63	39	40	583	5	1777
	IND	0	9	5	3	0	3	2	0	24	20	10	1	20	1	1	6	5	34	0	142
	REL	0	7	1	1	0	0	0	0	3	3	0	0	3	0	34	4	5	0	0	61
	GOV	0	0	0	0	0	1	1	0	3	4	0	0	2	0	3	0	0	11	0	27
	EDU	0	3	3	2	0	0	3	0	10	14	0	1	6	0	0	0	0	21	1	65
	OTHER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	4
	TOTAL	12,125	36	47	47	2	61	23	218	238	323	10	19	231	51	203	53	52	2,659	22	16,421
Height	1- 3	12,119	36	34	38	1	61	10	0	199	254	10	4	215	0	160	46	52	2,384	18	15,637
	4-7	7	0	6	6	1	0	13	203	25	41	0	3	16	45	43	7	0	276	4	698
	8+	0	0	8	3	0	0	0	14	14	28	0	12	1	6	0	0	0	0	0	86
	TOTAL	12,125	36	47	47	2	61	23	218	238	323	10	19	231	51	203	53	52	2,659	22	16,421
Year	≤1949	7,652	15	0	0	2	0	0	50	105	33	0	5	205	21	203	4	5	2,659	22	10,983
	1950-1970	3,793	17	41	22	1	18	5	42	101	137	9	6	26	7	0	43	41	0	0	4,307
	1971-2005	646	4	6	23	0	40	16	116	31	142	1	8	0	21	0	6	6	0	0	1,067
	≥2006	35	0	0	2	0	3	2	9	0	11	0	0	0	2	0	0	0	0	0	64
	TOTAL	12,125	36	47	47	2	61	23	218	238	323	10	19	231	51	203	53	52	2,659	22	16,421

*Material is known but not structural type **Unknown material or structural type

As an example of application, the conducted inventory was used for the seismic risk assessment study of the 1,220 buildings in Old Québec City (Abo El Ezz 2013), see Figure 6. The considered scenario event was of magnitude 6.2 and distance 15 km (M6.2R15) selected to match the National Building Code of Canada (NRC 2010) return period of 2%/50 years (Figure 7a). The applied risk assessment methodology was developed by Abo El Ezz (2013). The inventoried buildings were classified into 10 building classes (9 standard Hazus buildings classes with the addition of stone masonry) considering two seismic design codes: pre-code (before 1970) and mid-code (after 1970). Due to similar construction practices in Canada and in the United States, capacity curves and displacement based fragility functions reported in the Hazus technical manual (FEMA-NIBS 2003) were used for the vulnerability modeling of the considered structural types. For stone masonry buildings, the applied capacity curves and fragility functions were generated in a parallel study (Abo El Ezz et al. 2013).

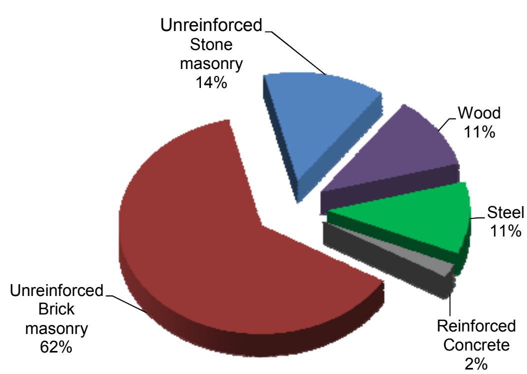


Figure 6 **:** Building inventory for the 1,220 buidlings in Old Québec City sector.

The seismic hazard for the M6.2R15 scenario was characterised with the spectral accelerations at 0.3s and 1.0s, as IMs representative for short and long period buildings, respectively. For the predominant soil type in Old Québec City site class B (rock), Sa(0.3s)=0.38g and Sa(1.0s)=0.07g. A summary of the buildings distribution by construction material and simulated damage states is given in Figure 7b. The total number of buildings that will experience certain degree of damage is 369, or 30%. Predictably, most of the expected damage will occur in the pre-code stone and brick masonry buildings. Approximately 39% of the stone masonry buildings (65 out of 168 buildings) and 33% of the brick masonry buildings (252 out of 765 buildings) will suffer various level of damage.

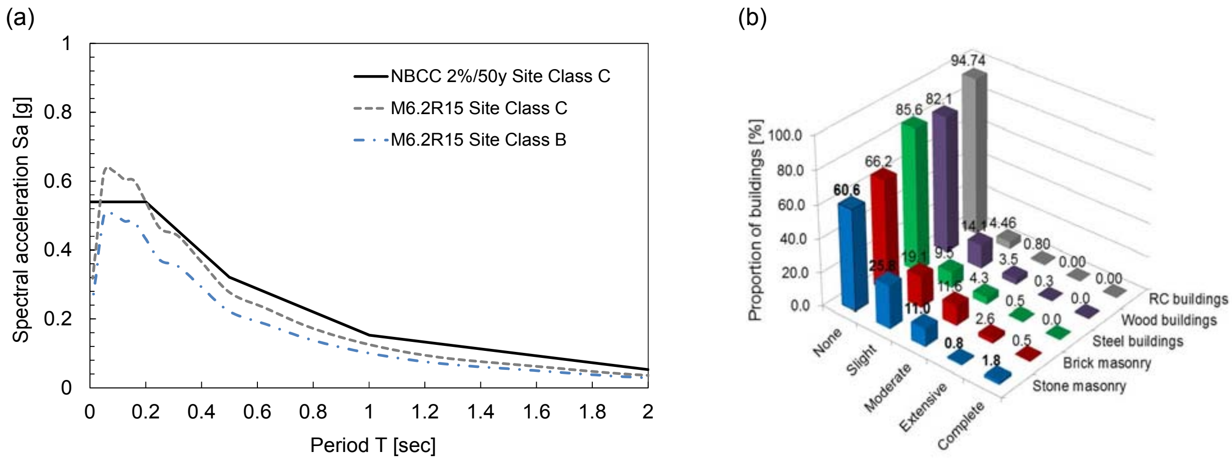


Figure 7 **:** M6.2R15 earthquake scenario: (a) Response spectra, (b) Proportion of buildings by construction material type in each damage state.

8 Conclusion

Inventory methodology was developed to increase efficiency and reduce subjectivity in collection of building inventory data in view of detailed urban seismic risk studies. The approach was based on statistical analysis of the available data in municipal property database for La Cité-Limoilou district in Québec City. A correlation was generated first between the probable structural types and occupancy, number of stories, and year of construction. It was combined with the study of the evolution of construction practices in Québec to produce the final inference matrix. The resulting inventory consisted of assigning the standard Hazus occupancy class and structural type to each of the existing buildings in the study area. The developed methodology was validated against the performed limited walking survey and collected engineering plans and drawings. It revealed as a rapid and efficient method which gives satisfactory results as good as or even better than the walking survey. This type of inference matrix could be used to define (along with other information) building inventory in other cities in Eastern Canada.

The conducted inventory for the Old Québec City (1,220 buildings) was used to perform a seismic risk study for a scenario earthquake M6.2R15 and study the damage distribution of stone masonry buildings, an important cultural heritage. The global inventory realised for the La Cité-Limoilou (16,421 buildings) is currently used to perform similar seismic risk study and evaluate the influence of inventory data on the damage distribution results.

Acknowledgements

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References

Abo El Ezz, A. 2013. *Probalistic seismic vulnerability and risk assessment of stone masonry structures*. Ph. D. Thesis, École de technologie supérieure, Montréal, Canada, 159 p.

Abo El Ezz, A., Nollet, M.-J. and Nastev, M. 2011a. Characterization of historic stone masonry buildings in Old Québec City for seismic risk assessment. *CSCE General Conference,* Ottawa, GC-223, 10 p.

Abo El Ezz, A., Nollet, M.-J. and Nastev, M. 2011b. Development of seismic hazard compatible vulnerability functions for stone masonry buildings. *CSCE 3rd Structural Specialty Conference*, Edmonton, 10 p.

Abo El Ezz, A., Nollet, M.-J. and Nastev, M. 2013. Seismic Fragility Assessment of Low-Rise Stone Masonry Building. To be published in *Journal for Earthquake Engineering and Engineering Vibration*, 12(1): 1-11

ATC 2002. *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook - FEMA 154 and Supporting Documentation - FEMA 155*, 2nd Ed. Redwood City, CA: Federal Emergency Management Agency.

Auger, J. 1998. *Mémoire de bâtisseurs du Québec : répertoire illustré de systèmes de construction du 18e siècle à nos jours*. Montréal, Éditions du Méridien, 155 p.

BANQ 1959. *Atlas des assureurs*. Bibliothèque et Archives Nationales Québec, on line www.banq.qc.ca.

Bourque, H. 1991. *La maison de faubourg : l'architecture domestique des faubourgs Saint-Jean et Saint-Roch avant 1845*. Québec, Institut Québécois de recherche sur la culture, 199 p.

FEMA-NIBS, 2003. *HAZUS-MH MR4: Multi-hazard Loss Estimation Methodology Earthquake Model Technical manual.* Federal Emergency Management Agency (FEMA), National Institute of Building Science (NIBS), Washington, D.C, 712 p.

French, S.P. 1991. A knowledge-based approach to using existing data for seismic risk assessment. *Urban and Regional Information Systems Association URISA-1991*, 226-237.

IRC-NRC 2010. *National Building Code of Canada*. Institute for Research in Construction, National Research - Council of Canada NRCC. Ottawa.

Jaiswal1, K.S. and Wald, D.J. 2008. Developing a global building inventory for earthquake assessment and risk management. *14th World Conference on Earthquake Engineering,* Beijing, Chine, 8 p.

Laframboise, Y., Hurtubise, L., La Grenade-Meunier, M. et Guimont, J. 1991. *La fonction résidentielle à Place Royage 1760-1820 - Synthèse*. Publications du Québec « Collection patrimoines », Ministère des affaires culturelles, available on line http://www.ourroots.ca.

Lessard, M. et Marquis, H. 1972. *Encyclopédie de la maison québécoise*. Montréal: Éditions de l'Homme.

Nollet, M.-J., Désilets, C., Abo El Ezz, A. et Nastev, M., 2012. *Approche méthodologique d'inventaire de bâtiments pour les études de risque sismique en milieu urbain / Ville de Québec, Arrondissement La Cité-Limilou*. Commission géologique du Canada, Dossier public DP7260, 93 p.

Ploeger, S.K. 2008. *Applying the HAZUS-MH software tool to assess seismic hazard and vulnerability in downtown Ottawa, Canada*. M.Sc. Thesis, Carleton University, Ottawa, 323 p.

Ploeger, S.K., Atkinson, G.M. and Samson, C. 2009. Applying the HAZUS-MH software tool to assess seismic risk in downtown Ottawa, Canada. *Natural Hazards*, 20 p.

Vallières, A. 1999. *Processus de transformation typologique du bâti résidentiel dans l'arrondissement historique du Vieux-Québec*. Mémoire de maîtrise, Université Laval, 221 p.

Yu, K. 2011. *Seismic Vulnerability Assessment for Montreal - An Application of HAZUS-MH4*. M.Eng. Thesis, McGill University, Montreal, Canada, 191 p.