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New Tools for the Seismic Vulnerability Assessment of Buildings in Ottawa, Ontario

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Abstract: Given the large stock of buildings in cities such as Vancouver, Montreal and Ottawa, there is an urgent need to assess the seismic vulnerability in Canadian urban areas. The collection of a well-developed building inventory can provide essential information for mapping the spatially variable seismic vulnerability within urban areas. This paper presents results from an on-going research program which forms part of a multi-disciplinary effort between the University of Ottawa's Hazard Mitigation and Disaster Management Research Centre and the Geological Survey of Canada (NRCAN) to facilitate the data collection and seismic vulnerability assessment of buildings in dense urban areas. A general building inventory and its spatial distribution and variability are key variables needed for earthquake loss assessment and risk management. The Urban Rapid Assessment Tool (Urban RAT) is designed for the rapid collection of building data in urban centres. The Geographic Information System (GIS) based assessment desktop and mobile toolset allows for intense data collection and revolutionizes the traditional sidewalk survey approach to collecting building data. To date, approximately 14,000 buildings have been assessed in 8 major downtown neighbourhoods. The following paper describes the application of the Urban RAT software to the downtown core of the City of Ottawa. Information pertaining to the condition of existing buildings including the spatial distribution and percentage breakdown of construction type, local soil conditions, occupancy class, year of construction, and irregular building configurations relevant to seismic risk assessments are presented.

1 Introduction

The exposure built infrastructure and developed urban areas to earthquakes presents a hazard to unprepared communities. A large proportion of the building inventory in Canada is resilient to seismic disturbance; however, there are also several areas that demand improvement. With 40% of Canadians living in areas of high or moderate risk of loss from an earthquake, such as Victoria, Vancouver, Montreal and Toronto, it is essential for individuals, businesses and governments to understand the potential hazards posed by seismic activity (Kovacs 2010). In the Ottawa-Gatineau region, continuous urban growth puts ever greater populations and infrastructure at risk to seismic disturbance (Lamontagne 2010). Therefore, there is a need to invest in research efforts to increase our knowledge and preparedness in order to mitigate potential seismic related loss. Earthquake loss estimations provide knowledge to support effective actions by decision makers that can reduce potential damages to urban communities. The contribution of this research is in seismic risk mitigation in Ottawa, Canada. We present a new set of Geographic Information System (GIS) and mobile tools that allow for rapid structural assessment in urban centres and demonstrate how the results can be used for risk assessment and mitigation for the building stock within the downtown core.

Geographic Information System (GIS) tools can facilitate rapid data entry, analysis and visualization of spatial data. GIS tools have been utilized in many emergency management applications (Herold and Sawada 2012) and they provide an efficient toolset for loss estimation studies (Tari and Tari 2002). As the consequences of an earthquake vary spatially, GIS-based mapping and analysis is the nexus that links the event of an earthquake with hazard specific information such as surficial geology (*cf.* Motazedian et. al. 2011) and structural variations. Success in mapping the spatial variability in seismic risk outcomes requires a well-developed database of building structures. Such a database can be effectively populated directly within a GIS system and, as such, GIS capabilities play an essential role in earthquake risk assessment.

Seismic risk estimations provide decision makers innovative information to deploy proper emergency response and mitigation procedures. In Canada, such efforts are being realized through efforts to provide satisfactory approximations that include the development building structural databases (Ventura et al. 2005). A well-developed building inventory hinges on the information that is collected. Detailed data collection forms and guidelines exist for loss estimations and populating inventory databases as outlined in FEMA 154 (ATC 2002) and HAZUS®MH (ABS Consulting and ImageCat 2006). They include parameters such as construction type and year of construction which are good indicators of performance and seismic code provisions respectively. Therefore, the information collected within a building inventory is essential to provide valued risk estimations.

This paper introduces a new desktop GIS extension and mobile counterpart as an integrated toolset that provides the capabilities necessary for rapid data collection of site-specific structural building parameters. The Urban Rapid Assessment Tool (Urban RAT) is designed for the rapid collection of building data in urban centres. The Geographic Information System (GIS) based assessment tool allows for intense data collection and revolutionizes the traditional sidewalk survey approach to collecting building data. This paper briefly describes the methodology and procedure used in Urban RAT and provides a summary of its relevance and application. We then present results related to the condition of existing buildings in the City of Ottawa that are relevant to seismic risk assessment of the downtown core.

2 Urban Rapid Assessment Tool (Urban RAT)

The Urban Rapid Assessment Tool (Urban RAT) suite modernizes the way building surveys are conducted. Rather than the traditional pen and paper sidewalk survey, the Urban RAT tool exploits the use of computers, web services and portable electronics in order to obtain and collect site specific building information.

Urban RAT is an ArcGIS-Google-Android system that contains two components: an in-lab application (add-in) built for ArcGIS 10.x within the .Net framework (in order to integrate ArcGIS and the Google API) and second, an on-site (Google Android) app that collects positional and visual information in addition to inputs that contain the same data. The on-site application data can be synchronized with the main ArcGIS database after data collection takes place off-site.

Within the lab, using a MS Windows PC with ArcGIS 10.x installed, the user is presented with a new toolbar called URAT (**Figure 1**)

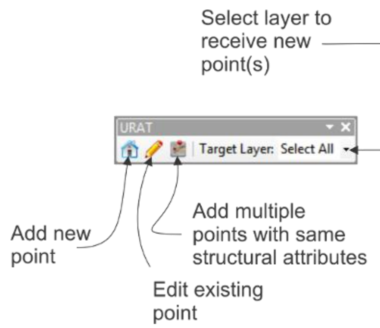


Figure 1: Urban RAT toolbar in ArcGIS 10.x (from Sawada et al., 2013)

Using this toolset, the user selects the simply clicks on a building represented on a satellite image within ArcGIS and this initiates two windows, one showing the form with building parameters to be entered (**Figure 2a**) and the second window opens Google Street View within ArcGIS at the location of the building that was selected (**Figure 2b**) allowing the assessor to examine the structure from many angles and enter parameters on the form. Once the form is complete the data is automatically saved into a new data layer with a point at the location of the assessment.

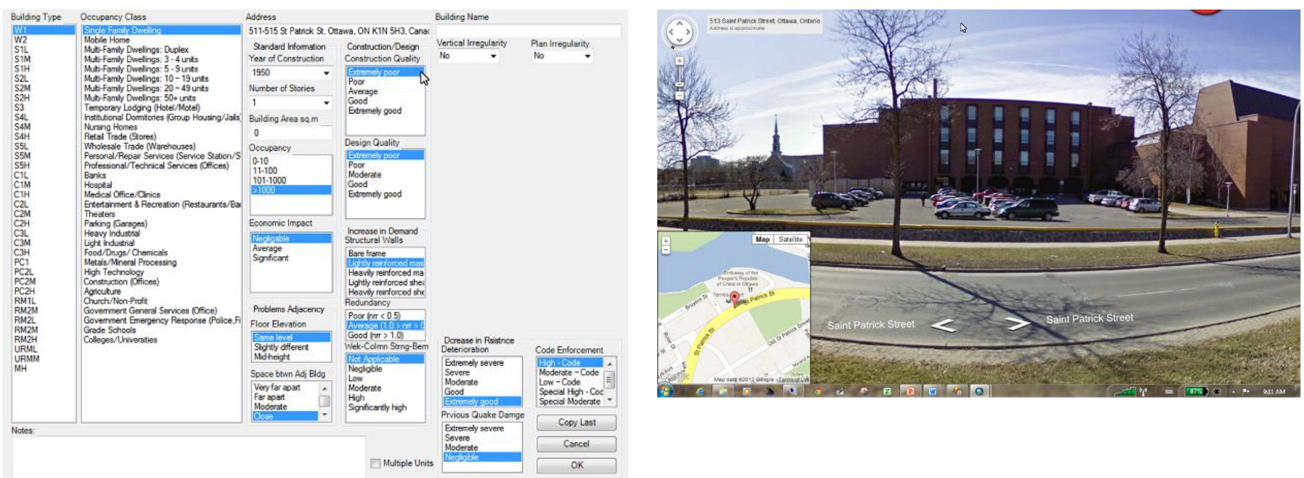


Figure 2: a) Building assessment form in Urban RAT; b) Google StreetView within Urban RAT and ArcGIS opened at location of building to be assessed (from Sawada et al. 2013)

Urban RAT suite's framework is designed to incorporate roughly 30 structural parameters. **Table 1** presents Urban RAT's assessment parameters and are based on FEMA 154 (ATC 2002) and FEMA 310 (ASCE 1998). The first theme ([1] General information) provides the basic information related to a buildings characteristics and structural system. The second and third themes ([2] Increase in Demand and [3] Decrease in Demand) represent endogenic engineering parameters which influence building vulnerability during earthquake events. The final theme ([4] Issues of Adjacency) incorporates an imperative exogenic factor that can affect structural performance during earthquake ground shaking. Themes [1]-[4] are required for high resolution earthquake loss estimation studies. These variables and their respective values are presented to the user on the main Urban RAT interface (**Figure 2 & 3**).

Table 1: Urban RAT theme parameters for assessment

[1] General	
Building Type	Year of Construction
Address	Number of Stories
Name of Building	Occupancy Class

Vertical Irregularity Plan Irregularity Construction Quality	Occupancy Economic Impact Design Quality
[2] Increase in Demand	
Structural Walls Redundancy	Weak Column-Strong Beam
Plan Irregularity	
Diaphragm Continuity Re-Entrant Corners	Torsional Irregularity
Vertical Irregularity	
Short Column Effect (Captivated Column)	Soft Story Weak Story
[3] Decrease in Resistance	
Deterioration (e.g. Corrosion) Damaged from Previous Earthquake	Code Enforcement
[4] Issues with Adjacency	
Floor Elevation	Space Between Adjacent Buildings

In some cases, the assessor will find that the Google StreetView does not yield sufficient information. As such, a mobile version of the virtual site assessment software can be used and will run on any certified Google Android tablet. There is no need to have an active wireless internet connection (Wi-Fi, 3G, 4G or otherwise) with Urban RAT mobile in order to make full use of the tablet's GPS and mapping functions. In Urban RAT mobile (**Figure 3**), all data is stored locally on the device as XML and CSV files which can be easily uploaded to the main ArcGIS program when the user returns to the desktop.

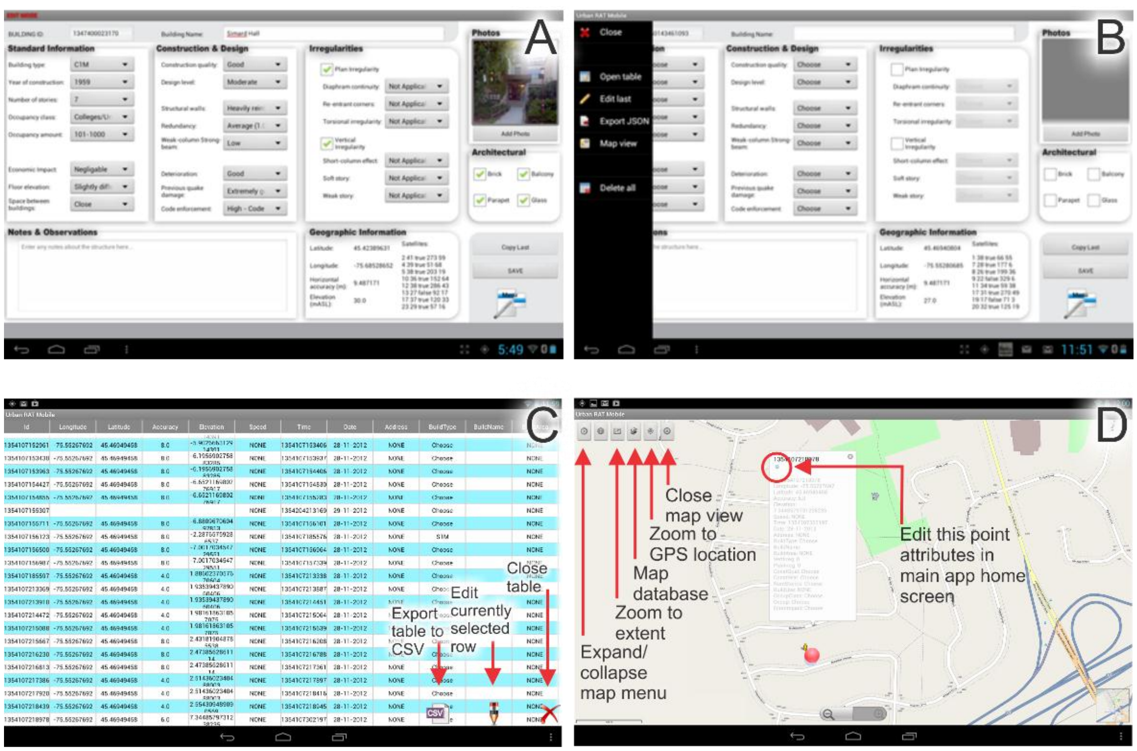


Figure 3: Urban RAT mobile: a) Main assessment screen, variables as in Table 1; b) Main menu used to switch between data entry screen, map and data table; c) Data table of stored assessment locations. User can edit or export to comma separated values file (CSV); d) Map of assessment area. User can plot all assessed points, select individual points for editing and see current location on map using GPS receiver in tablet.

For further information on details of the development and use of the Urban RAT suite refer to Sawada et al. (2013).

2.1 Urban RAT in Practice

The Urban RAT tool was used to create a building database for the downtown core of the City of Ottawa. The following neighbourhoods were the primary focus for assessment: Centretown, West Centretown, Byward Market, Lowertown, Sandy Hill, Ottawa East, Glebe – Dows Lake and Ottawa South. Currently, the number of buildings assessed comprises of 13,646 buildings. In general, most downtown neighbourhoods in the City of Ottawa contain a combination of historical and modern buildings.

2.1.1 Construction Type

The construction type of a building influences its seismic performance. **Figure 4a** presents the spatial distribution of construction type within the research area. A building is expected to exhibit a brittle or ductile response in the incident of an earthquake as a function of the engineering and type of material utilized for construction. Modern engineered buildings in seismic areas are specifically designed to withstand expected lateral loads and perform better than non-engineered buildings. At the same time, the seismic performance of engineered building will depend on earthquake hazard and the level of building code (refer to section 2.1.4). Typically reinforced concrete or steel buildings fall in the category of engineered buildings. More recent timber and reinforced masonry construction can also be included in this category due to the development of design standards, however older unreinforced masonry buildings can be considered non-engineered construction (usually built from prescriptive methods). For the buildings assessed in this study, reinforced concrete, reinforced masonry and steel buildings were considered engineered construction while unreinforced masonry and wood buildings were classified as non-engineered. As shown in **Figure 4b**, the majority of buildings assessed in this study can be classified as non-engineered buildings while approximately 6% of the building stock is categorized as engineered. Of particular concern is the large inventory of unreinforced masonry buildings, a structural material which has consistently demonstrated poor performance in past earthquakes. In addition, it is noted that a large inventory of residential single family dwellings built of wood were included in the assessment.

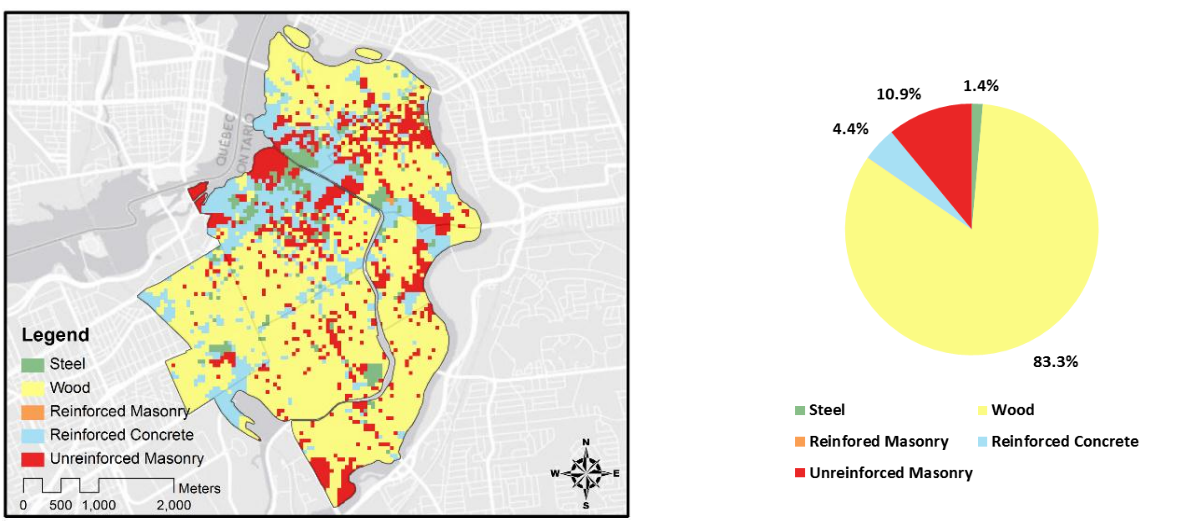
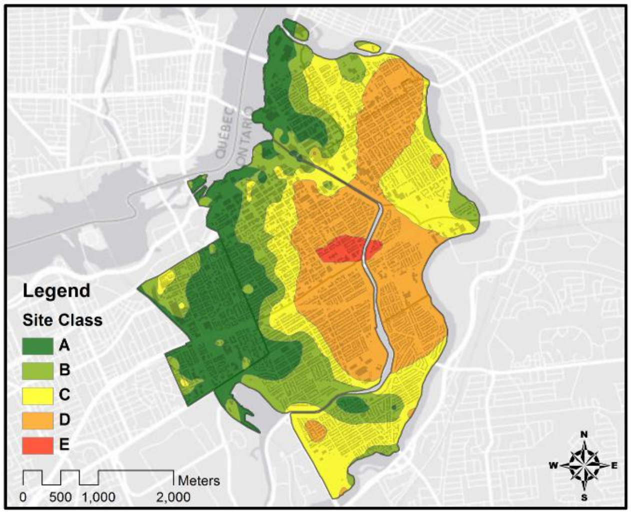


Figure 4: Construction Type of buildings in Ottawa, Ontario: a) Spatial Distribution; b) Numerical Breakdown

2.1.2 Site Soil Classification

The local ground conditions in which a building rests is a key indicator to ground shaking intensities due to amplification/deamplification of seismic waves during the event of an earthquake. In hard rock ground conditions (soil profile A; **Figure 5a**), a lower amplitude is typically exhibited in comparison to soft or stiff soil ground conditions (soil profile D & E; **Figure 5a**), where the amplification of seismic waves increases the likelihood of damage due to an increase in ground shaking. (*cf.* Motazedian et. al. 2011). The soil conditions within Ottawa are spatially variable as depicted in **Figure 5a** (*cf.* Hunter et al. 2010). Approximately 36.3% (**Figure 5b**) of the buildings assessed using Urban RAT are constructed on soft or stiff soil conditions while the remainder of the building stock are constructed on hard rock or very dense soil profiles.



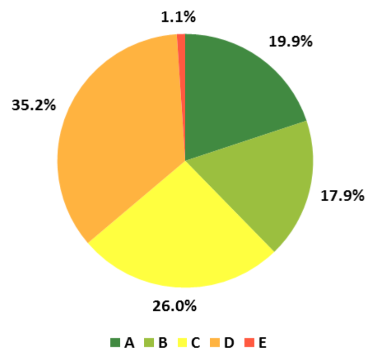


Figure 5: Site Soil Classification of buildings in Ottawa, Ontario: a) Spatial Distribution; b) Numerical Breakdown

2.1.3 Building Importance

The level of importance of a building can be established on the basis of the building's occupancy and use. **Figure 6a** illustrates the spatial variance of occupancy class within the building inventory. The NBCC classifies an importance factor dependent on the building's occupancy when determining the total seismic base shear the building is designed to resist. The categories include normal, high and post-disaster importance classifications. High importance structures include schools and community centres that are able to house a large number of individuals. Post-disaster buildings include hospitals and emergency response facilities that are required to remain operational in the event of a disaster. Normal importance buildings include all other buildings that do not fall in the high or post-disaster categories (NRCC 2010). Within the building stock, high importance and post-disaster buildings represent 0.7% and 0.2% of the total building stock respectively (**Figure 6b)**.

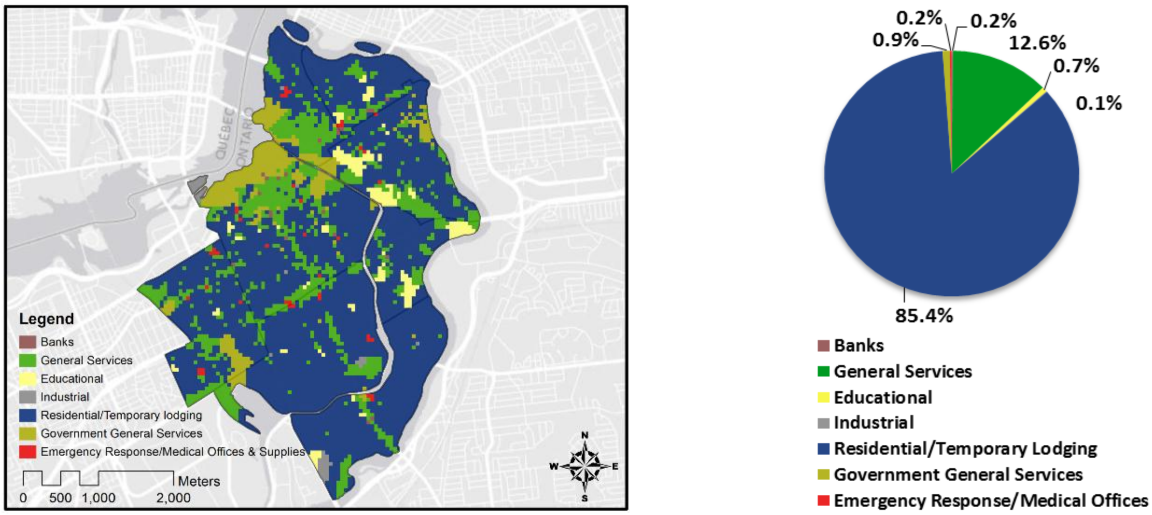


Figure 6: Occupancy Class of buildings in Ottawa, Ontario: a) Spatial Distribution; b) Numerical Breakdown

2.1.4 Year of Construction

As mentioned previously, one very important factor affecting seismic performance is the building year of construction. **Figure 7** displays a breakdown of the year of construction of buildings in the downtown region of Ottawa. The original design drawings of a building and/or supplementary information such as census dissemination area age of construction or tax records can be useful in defining the year of construction. The year of construction, when considered with historical development of building code seismic design criteria, can provide insight on the seismic design loads and level of seismic design and detailing of a building. In order to determine seismic vulnerability, it is important to understand the development of the seismic design code provisions over the years. According to NIBS (1999) and Tesfamariam and Saatcioglu (2008), the "level of building code can be divided into three distinct states for North America: low code (Pre 1941), moderate code (Between 1941 and 1975) and high code (Post 1975)." Considering this breakdown, analysis of the building inventory reveals that the vast majority of the building stock was built prior to 1940, indicating most of the buildings in compliance with low code provisions.

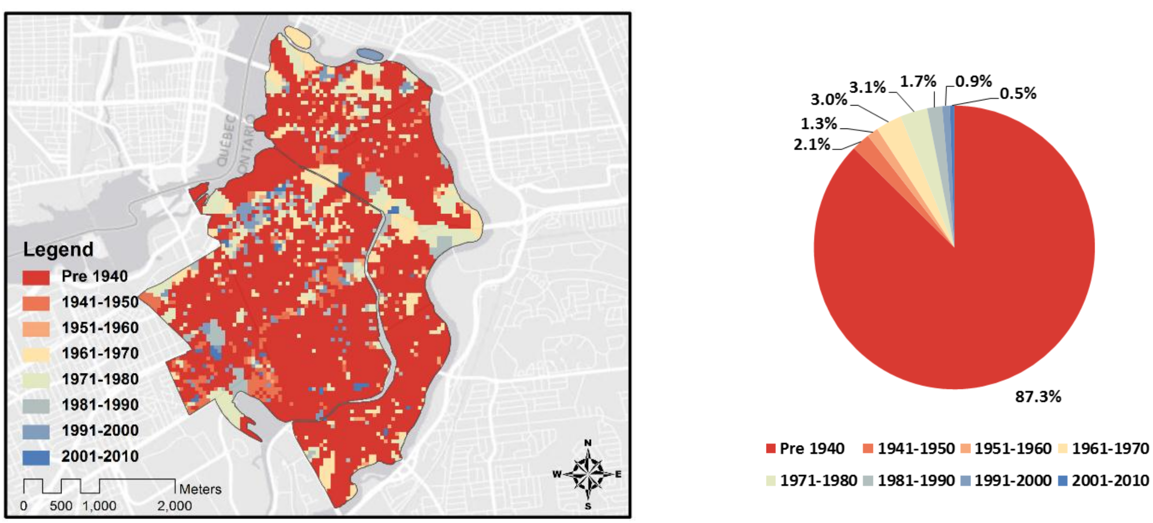


Figure 7: Year of Construction of buildings in Ottawa, Ontario: a) Spatial Distribution; b) Numerical Breakdown

2.1.5 Building Irregularity

Performance of buildings in past earthquakes has demonstrated that buildings with irregular configuration or irregular distribution of structural properties can cause an increase in seismic demand, leading to a greater degree of damage and greater risk of failure of a building. (Tesfamariam and Saatcioglu 2008). Therefore, in the development of the NBCC seismic provisions to better evaluate seismic demand, rules have provided for the classification of buildings into various irregular categories as a function of asymmetries (NRCC 2010). Accordingly, these parameters that evaluate structural irregularities have been accounted for in the Urban RAT building inventory as seen in **Figure 8a**. The two principal types of irregularity assessed include plan and/or vertical irregularities of a structure with 5.5% of the downtown building stock classified as containing irregular configurations (**Figure 8b**).

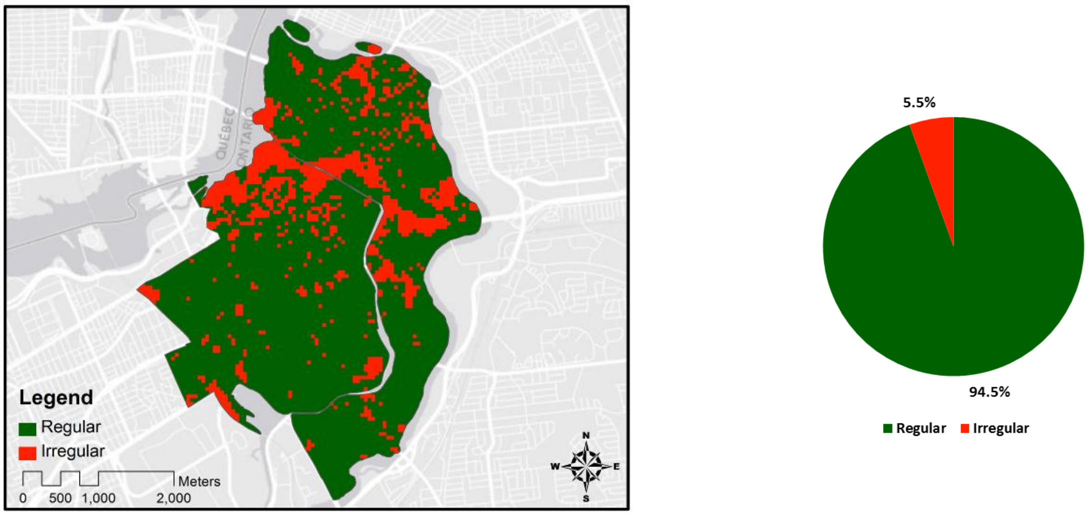


Figure 8: Regular vs. Irregular buildings in Ottawa, Ontario: a) Spatial Distribution; b) Numerical Breakdown

3 Loss Estimations

Two existing programs that are compatible for Canadian scenarios are HAZUS-MH and CanRisk. HAZUS-MH is a comprehensive software originally developed by the Federal Emergency Management Agency of the United States, and the National Institute of Buildings Sciences (see FEMA and NIBS 2006). With an upsurge in Canadian interest in HAZUS-MH, an agreement was signed in August of 2011 between FEMA and Natural Resources Canada to adapt the HAZUS-MH program to Canada. CanRisk is a Canadian engineering program developed by CSRN (Canadian Seismic Research Network) researchers that integrates site specific spatial information such as NEHRP-based soil conditions and ground motion with detailed user-input building-specific data. CanRisk is modular in that it can include modules to evaluate risk of various aspects of the built environment. Currently, the program includes a module to evaluate reinforced concrete buildings (Tesfamariam and Saatcioglu 2010) and work is currently in progress to include unreinforced masonry and other construction material types. The program output establishes the damage level and risk index for a given building as well as a high resolution snapshot of the structural performance. Work is currently underway to integrate the data collected from Urban RAT into the framework of CanRisk by developing a custom GIS extension.

4 Conclusions

As the population of Canada increases, especially in metropolitan areas such as Vancouver, Toronto, Montreal and Ottawa, the preparedness of a built environment and its exposure to natural hazards such as earthquakes plays a critical factor to the development of a community's resilience. Data collection of the building stock in a major urban centre facilitates various aspects of emergency awareness and mitigation as the resultant data supports seismic risk assessment and earthquake loss estimation. Many urban centres contain a large building stock, therefore software and hardware tools that can expedite data collection are fundamental to timely seismic risk mitigation decisions. The Urban RAT suite can better equip regions to mitigate and prepare for, respond to, and recover from natural hazards like earthquakes. The advancements in data processing and GIS has provided the foundation for the development of comprehensive loss estimation programs such as HAZUS-MH and CanRisk that can better serve decision makers in Canada. The City of Ottawa, an area of moderately high seismic risk, has a population of almost one million people and it is essential to evaluate distribution of seismic risk across the city, especially within heavily populated and historical regions such as the downtown core. This paper presented the preliminary results from the use of Urban RAT, a GIS-based tool that can be used to rapidly collect building data in dense urban areas. The tool was used to collect data from a large stock of buildings within the City of Ottawa.

The highlights of the Urban RAT suite and its application to the building stock in the City of Ottawa as presented in this paper are summarized below:

- Urban RAT is developed on a synchronized ArcGIS-Google-Android platform which allows for both in-lab/ virtual assessments and in-field /on-site assessments to be performed in tandem;
- The ability to perform in-lab/virtual site assessments as well as the auto-fill function embedded in the digital form optimizes time and efficiency of data collection;
- The inclusion of engineering parameters based on FEMA 154 (ATC 2002) and FEMA 310 (ASCE 1998) provides data which can be used in loss estimation programs, and the potential to build a very well-developed building inventory across a large urban area;
- Within the building inventory, 5.8% of building are classified as engineered building while the remainder are non-engineered building built from prescriptive methods. This is a result of a large inventory of residential single family dwellings included in the assessment;
- 36.3% of the building stock is constructed on soft/stiff soil profiles that include an increased ground shaking characteristics during the event of an earthquake;
- Approximately 1.0% of the building stock is classified as high importance or post-disaster categories;
- 87.3% of buildings in the downtown core were built prior to 1940 (prior to the development of seismic design criteria), and thus need to be evaluated to ensure a satisfactory degree of safety in the event of a large magnitude earthquake;
- 5.5% of buildings are tagged as including an irregular structural configuration. Building irregularity is an important parameter that must be identified to assess the performance of buildings during earthquakes;
- Information and data collected from Urban RAT as presented in this study can be utilized in earthquake loss estimation models such as HAZUS and CanRisk to provide high resolution loss estimations which can ultimately be used in disaster management and mitigation programs.

Acknowledgements

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