GEM Building Taxonomy – an open global building classification system

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ABSTRACT: An innovative, globally applicable Building Taxonomy was developed for the Global Earthquake Model (GEM) to consistently describe and classify buildings worldwide as a key step towards assessing their seismic risk. The Taxonomy was designed to be relevant to the seismic performance of different construction types; be comprehensive yet simple; be collapsible; and adhere to principles that are familiar to the range of users. The Taxonomy's potential applications extend beyond seismic risk – it can be readily extended to other hazards, and can also be used to facilitate global collaboration on the diversity of vulnerability of the world's existing buildings. This paper briefly describes the Taxonomy and its development, explains its international testing and gives recent examples of its implementation in various countries. The Building Taxonomy and Glossary are available at http://www.nexus.globalquakemodel.org/gem-building-taxonomy/overview.

1 THE GLOBAL EARTHQUAKE MODEL (GEM)

The Global Earthquake Model (GEM) is an initiative to develop a global model of earthquake risk as an open source, community-driven project. It has been developed by the GEM Foundation since 2009 in response to a critical need for state-of-the-art information on earthquake risk covering all areas of the world as a necessary first step towards risk awareness and mitigating action. GEM seeks to make earthquake risk information accessible to a wide spectrum of end-users (engineers, researchers, risk managers, urban planners, insurers/reinsurers, civil protection departments, and international and non-governmental organisations, amongst others) and their beneficiaries. This need was underlined by a call from the Organisation for Economic Cooperation and Development's (OECD) Global Science Forum for the development of open-source risk assessment tools, and confirmed by a variety of institutions and organisations, the scientific community and public opinion (Crowley et al 2013). During its first implementation phase (2009-2014), GEM and its global network of collaborators have developed uniform datasets, state-of-the-art methodologies and a suite of well-documented tools, including the OpenQuake-engine (Silva et al 2014), the open-source software for seismic hazard and risk analysis. GEM has started its second programme (2014-2018), which comprises activities related with the improvement and creation of regional models and datasets, with the purposes of developing disaster risk reduction (DRR) actions. Some of these initiatives cover several countries (e.g. South America, Sub-Saharan Africa), which strengthens the need for uniform standards to characterize the elements exposed to the seismic hazard, such as the Building Taxonomy presented herein.

2 THE RELATIONSHIP OF THE BUILDING TAXONOMY TO GEM'S GLOBAL RISK COMPONENTS

During its first implementation phase, GEM has supported five global projects relating to seismic hazard, and another five global projects focused on seismic risk (Pinho 2012). The latter set of initiatives included a Global Exposure Database – GED (information regarding the residential building stock with four levels of detail); the Inventory Data Capture Tools – IDCT (suite of tool and protocols to develop exposure models from field information or satellite imagery); the Earthquake Consequences Database – ECD (a detailed collection of information from 73 past events); a Physical Vulnerability Database and Guidelines (a collection of hundreds of existing vulnerability functions and guidelines to derive new models); and finally, the subject of this publication, a Building Taxonomy. Several technical reports describing these five global projects can be found in the resources section of the GEM website (www.globalquakemodel.org/resources/publications/technical-reports/).

The Building Taxonomy assumes a special role, as it establishes the common language used between the different global components. For example, currently a user of the OpenQuake-platform (https://platform.openquake.org/) can find exposure models on GED, whose assets have been classified according to this taxonomy. If no information is found on this database, a user might choose to collect data using one of the IDCT products, which classifies each asset using the same taxonomy. Then, considering the building classification of each asset in the exposure model, it is possible to search for damage data from previous events on the ECD, or for existing physical vulnerability models on the Vulnerability Database. Thus, it is fair to state that the GEM Taxonomy enables an interaction with these four components, making them a unique source of earthquake information.

3 THE BUILDING TAXONOMY

3.1 Why is a building taxonomy needed?

Currently we do not have one internationally unified or standardized system of classification for buildings; or rather, we have numerous systems, each created to serve a special purpose. Examples of building classifications are those used for building codes, for fire protection, seismic design and energy efficiency. Many of these classifications are specific to only one country or region, are often overlapping, and with much mixing of concepts. In order to address these shortcomings, the GEM Building Taxonomy was developed using the following criteria:

International in scope. As far as possible, the Taxonomy should be appropriate for any region of the world. It should not favour any one region but rather be technically and culturally acceptable to all regions.

Detailed. The Taxonomy must include as many features as feasible that are relevant to, initially, the seismic, and later, other performance objectives of a building located anywhere in the world. The Taxonomy captures all aspects of the seismic performance and losses for an entire building, excluding non-structural components, the "before" and "after" states of common seismic retrofits, and between "ductile and non-ductile" systems.

Collapsible. A taxonomy is collapsible if taxonomic groups can be combined and the resulting combination still distinguishes differences in seismic performance from other combinations, albeit with some loss of precision (e.g., hawks, eagles, buzzards, harriers, kites are all raptors).

Extensible. All future data needs cannot be foreseen, so the Taxonomy has to lend itself to future extensions – i.e., be 'growable'. In the future the Taxonomy, if required, should be able to grow to include hazards such as flood, wind, volcanoes, fire and explosion, hazardous material release, and biohazards. Beyond such hazards, there are many other taxonomic needs, such as energy efficiency, interior pollutants, life-cycle considerations, habitability, and accessibility requirements, all of which could be addressed in theory by a unified Taxonomy.

User-friendly. The Taxonomy should be straightforward, intuitive, and as easy to use as possible, by both those collecting data, those arranging for its analysis and those who are end users.

3.2 Development of the taxonomy

The Taxonomy was developed in conjunction with other GEM researchers and builds on the knowledge base from other taxonomies, including the EERI and IAEE World Housing Encyclopedia, PAGER-STR, and HAZUS.

In order to develop the GEM Building Taxonomy, key tasks in the development process have been to:

i. review existing taxonomies,

ii. develop the taxonomy, and

iii. validate the taxonomy on a global level.

A literature review of existing taxonomies was performed at the initial development stage of the Taxonomy. The review revealed a significant number of existing structural/building taxonomies, which were mostly developed in the context of earthquake-related projects and initiatives. Most of these taxonomies have a regional or a country-based focus, and only two taxonomies (PAGER-STR and WHE) have the intent of describing global building stock. Taxonomies from other fields, such as the insurance or construction industries, were of lesser relevance for development of the Taxonomy.

The initial (Beta 0.1 version) of the Taxonomy had approximately 60 attributes, and was released in April 2011 following the discussions and critique at the first Workshop held in Berkeley (March 3 and 4, 2011). A rather complete description of a unique building can be generated when all attributes are populated with data. However, such a taxonomy was perceived as too detailed for its intended purposes. The Taxonomy was substantially revised following the feedback received from the GEM Global Component project teams and participants at the second Workshop held in Pavia, Italy (May 25, 2011). The subsequent version V1.0 was released in March 2012 and had 8 basic attributes required by all GEM Risk components: i) material of the lateral load-resisting system, ii) lateral load-resisting system, iii) roof, iv) floor, v) height, vi) date of construction, vii) structural irregularity, and viii) occupancy. The current version 2.0 was created following feedback received from GEM researchers in September and October 2012 (Brzev et al 2013). Five additional attributes were proposed as a result of the application of the V1.0 taxonomy by GEM researchers: namely, direction, building position within a block, shape of the building plan, exterior walls, and foundation.

3.3 Structure of the Building Taxonomy

The Taxonomy is organized as a series of expandable tables, which contain information pertaining to various building attributes. Each attribute describes a specific characteristic of an individual building or a class of buildings that could potentially affect their seismic performance. The following 13 main attributes have been included in the GEM Building Taxonomy Version 2.0 (v2.0):

1. Direction - this attribute describes the orientation of building(s) with different lateral load-resisting systems in two principal horizontal directions of the building plan perpendicular to one another.

2. Material of the lateral load-resisting system - e.g. "masonry" or "wood".

3. Lateral load-resisting system - the vertical structural system that provides resistance against horizontal earthquake forces, e.g. "wall", "moment frame", etc.

4. Height - building height above ground in terms of the number of storeys (e.g. a building is 3-storeys high); this attribute also includes information on the number of basements (if present) and the ground slope.

5. Date of construction or retrofit - identifies the year when the building construction was completed.

6. Occupancy - the type of activity (function) within the building; it is possible to describe a diverse range of occupancies - for example, residential occupancies include informal housing as well as high-rise apartment buildings.

7. Building position within a block - the position of a building within a block of buildings (e.g. "detached building" is not attached to any other building).

8. Shape of the building plan - e.g. L-shape, rectangular shape, etc.

9. Structural irregularity - a feature of a building's structural arrangement, such as one storey

significantly higher than other stories, an irregular building shape, or change of structural system or material that produces a known vulnerability during an earthquake. Examples: re-entrant corner, soft storey, etc. In recognition of the fact that a building can have more than one irregularity, the user is able to identify primary and secondary irregularities.

10. Exterior walls - material of exterior walls (building enclosure), e.g. "masonry", "glass", etc.

11. Roof - describes the roof shape, material of the roof covering, structural system supporting the roof covering, and roof-wall connection. For example, roof shape may be "pitched with gable ends", roof covering could be "tile", and roof system may be "wooden roof structure with light infill or covering".

12. Floor - describes floor material, floor system type, and floor-wall connection. For example, floor material may be "concrete", and the floor system may be "cast in-place beamless reinforced concrete slab".

13. Foundation system - that transmits loads from the building to the underlying soil. For example, a shallow foundation supports walls and columns in a building with hard soil conditions, and a deep foundation needs to be provided for buildings located in soft soil areas.

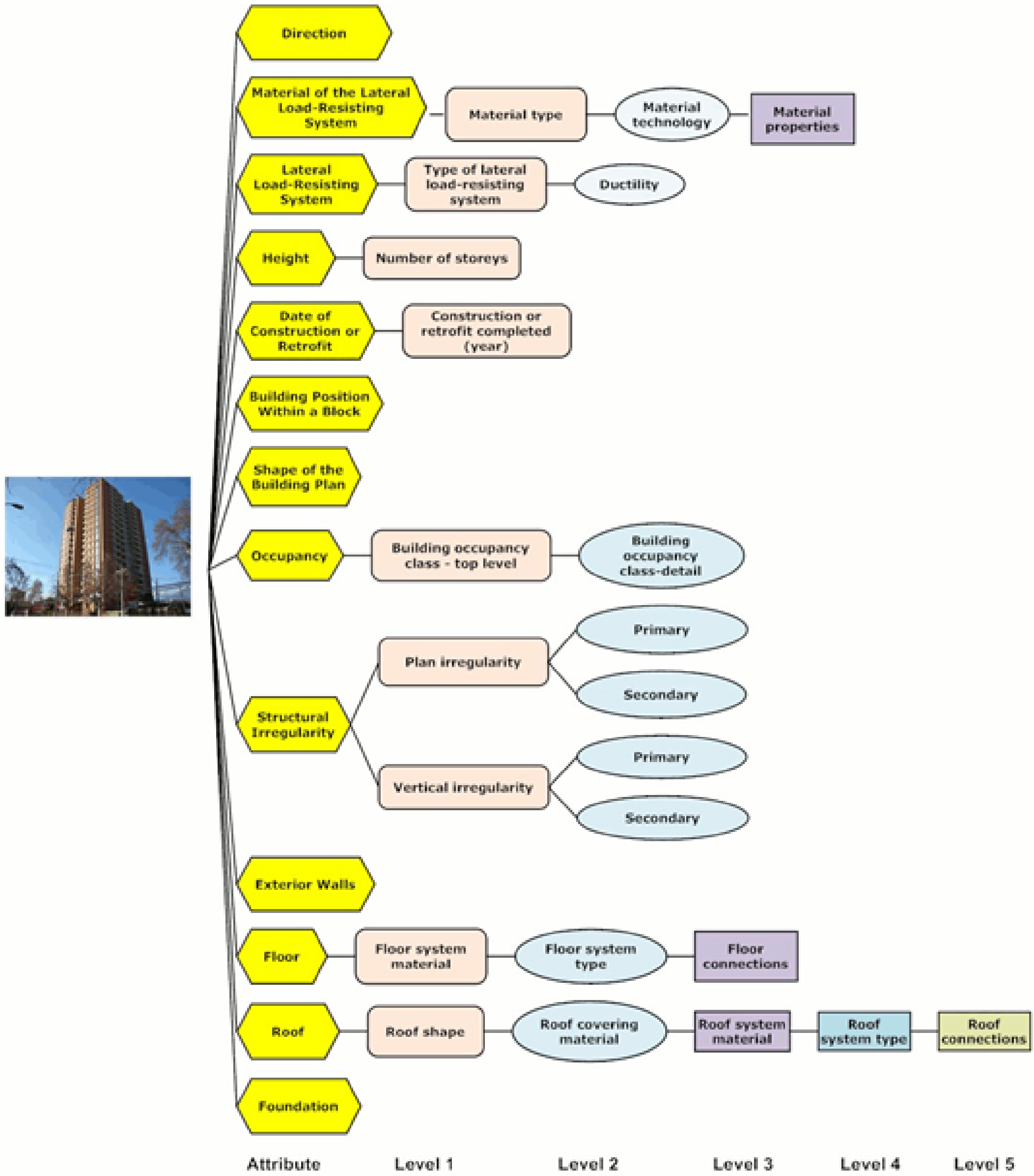


Figure 1. GEM TaxonomyV2.0: 13 attributes and different levels of detail.

The selection of these attributes was made based on the collective experience of the GEM Building Taxonomy team and other GEM Risk researchers, and is supported by numerous references, ranging from research papers and reports to evidence from past earthquakes. A brief explanation of the rationale behind the selection is described in the Taxonomy report (Brzev et al 2013).

Each attribute has been described by one or more levels of detail, referred to here as Level 1, 2, 3, etc. (Figure1). Some attributes (e.g. Direction, Building Position within a Block, etc.) have only one level of detail, while others (e.g. Roof) have five levels. It should be noted that a few attributes provide information useful for other natural hazards. For example, roof connections information in the Roof attribute may be useful for assessing risk of hurricane damage, and height of ground floor level above grade (Height attribute) may be useful for assessing flooding risk.

Table 3: Lateral Load-Resisting System

ID	Level 1 (L2)	ID	Level 2 (L2)
	Type of lateral load-resisting system		System ductility
Attribute_Type_Code	LLRS		LLRS_DUCT
L99	Unknown lateral load-resisting system	DU99	Ductility unknown
LN	No lateral load-resisting system	DUC	Ductile
LFM	Moment frame	DNO	Non-ductile
LFINF	Infilled frame	DBD	Equipped with base isolation and/or energy dissipation devices
LFBR	Braced frame		
LPB	Post and beam		
LWAL	Wall		
LDUAL	Dual frame-wall system		
LFLS	Flat slab/plate or waffle slab		
LFLSINF	Infilled flat slab/plate or infilled waffle slab		
LH	Hybrid lateral load-resisting system		
LO	Other lateral load-resisting system		

Figure 2. An example of an attribute table from the taxonomy, for lateral load resisting system.

Due to its ability to represent building typologies using a shorthand form, it is also possible to use the taxonomy for non-database applications, including possible applications or adaptation for Building Information Modelling (BIM) systems, and for the insurance industry. The proposed taxonomy scheme is flexible, providing opportunities for adding and/or modifying attributes depending upon the level of detail required and new knowledge gained through the data collection process. This is an advantage over alternative taxonomy models considering the global scope of the GEM initiative.

The Taxonomy is accompanied by two supplementary resources described in more detail below. All terms are explained in a companion online Glossary, which provides both text and graphic descriptions. The Taxonomy is also accompanied by TaxT, a computer application that enables a user to record information about a building or a building typology using the attributes of the Taxonomy.

The Taxonomy report explains how the GEM Building Taxonomy can be mapped to previous structural taxonomies as: PAGER-STR, the World Housing Encyclopedia and the European Macroseismic Scale (98); enabling previously captured information to be incorporated into GEM.

4 THE TAXONOMY GLOSSARY

The glossary for the Taxonomy (the Glossary) has been developed as a companion to the GEM Building Taxonomy V2.0. The Glossary provides definitions for all attributes contained in the Taxonomy. The Glossary is intended to be referred to in conjunction with the Taxonomy, and its main purpose is to explain and clarify the meaning of attributes and their details for users. Each glossary term contains a text description, and most terms contain one or more illustrations (photos and / or drawings) (Figure 3). The glossary includes more than 370 terms and 760 illustrations.

The Glossary is presently available in two forms: an interactive online version and a report version. The online version is posted on the NEXUS platform and is suitable for alphabetical search. All glossary terms are also hyperlinked from the attributes in the Taxonomy tables. In the report describing the glossary (Allen et al 2013), the glossary definitions are listed in alphabetical order, followed by the Taxonomy tables, which are included in the appendix.

The Glossary is a living document and it is expected to grow in future, particularly in terms of photographs illustrating features of global building stock. Members of the GEM community are invited to enrich the Glossary by contributing their photographs. Feedback can be submitted in the comments section of the web-based definitions, and comments of a more general nature can be submitted directly to the authors via the NEXUS platform. The GEM Building Taxonomy team has recognized a diversity of technical terminology used to describe the glossary terms - an example is the term “Moment Frame” which currently has five variants. The Variants (synonyms) section within the current Glossary will be expanded over time to include terms used in various countries.

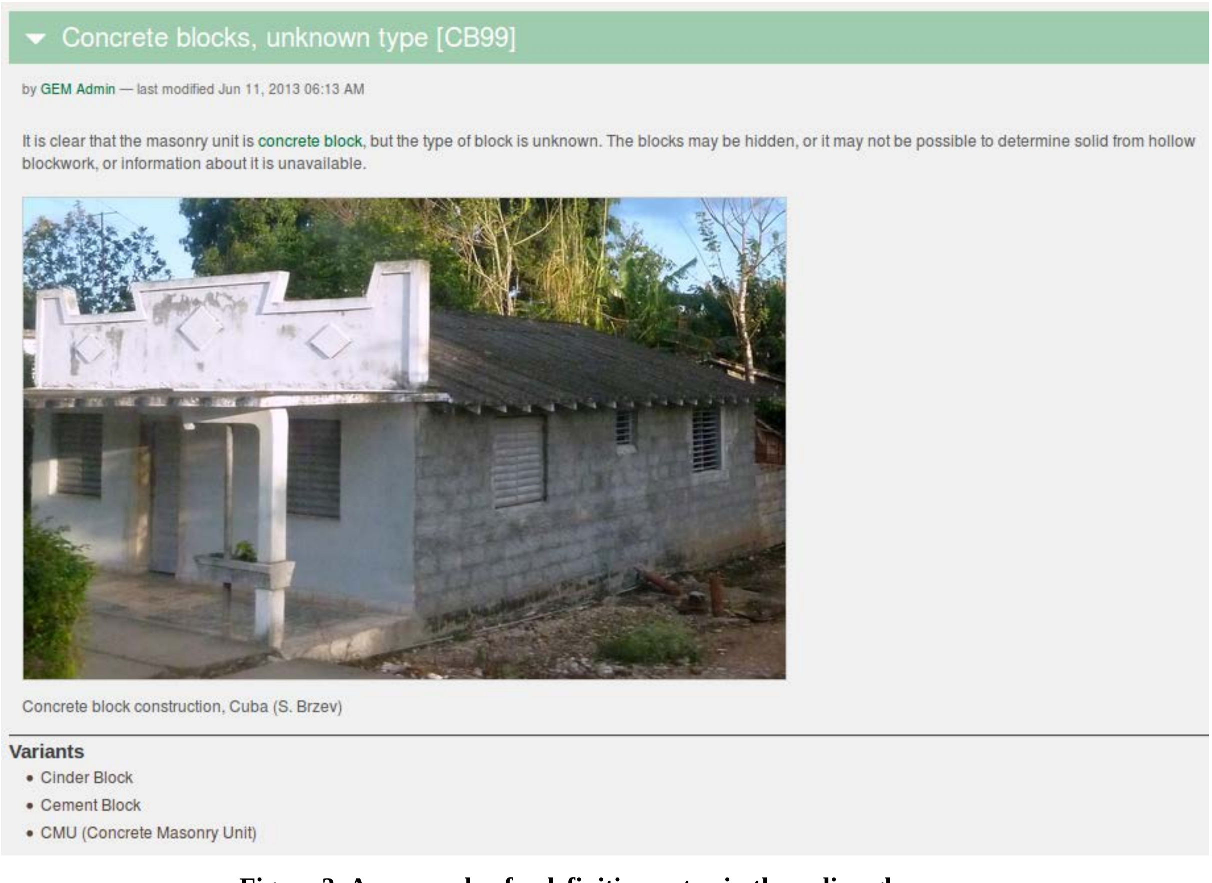


Figure 3. An example of a definition entry in the online glossary.

5 GEM BUILDING TAXONOMY TESTER (TaxT)

It is expected that the Taxonomy will be primarily used in computer applications. TaxT Version 4.0 enables a user to record information about a building or a building typology using the 13 attributes of the Taxonomy (Silva 2013) (Figure 4). TaxT also generates a taxonomy string corresponding to the information entered by the user for each building typology. In addition, TaxT enables a user to generate a report in PDF format which summarizes the attribute values they have chosen as representative of the building typology under consideration. The report may also include a photo of the building, and a text box where comments can be entered. An electronic version of TaxT is posted on GEM NEXUS web site (www.nexus.globalquakemodel.org/gem-building-taxonomy/posts/apply-the-gem-building-taxonomy-v2.0-using-taxt) and versions for mobile devices have also been developed. In addition, there is a web-based version that can be used to generate taxonomy strings (https://taxtweb.openquake.org).

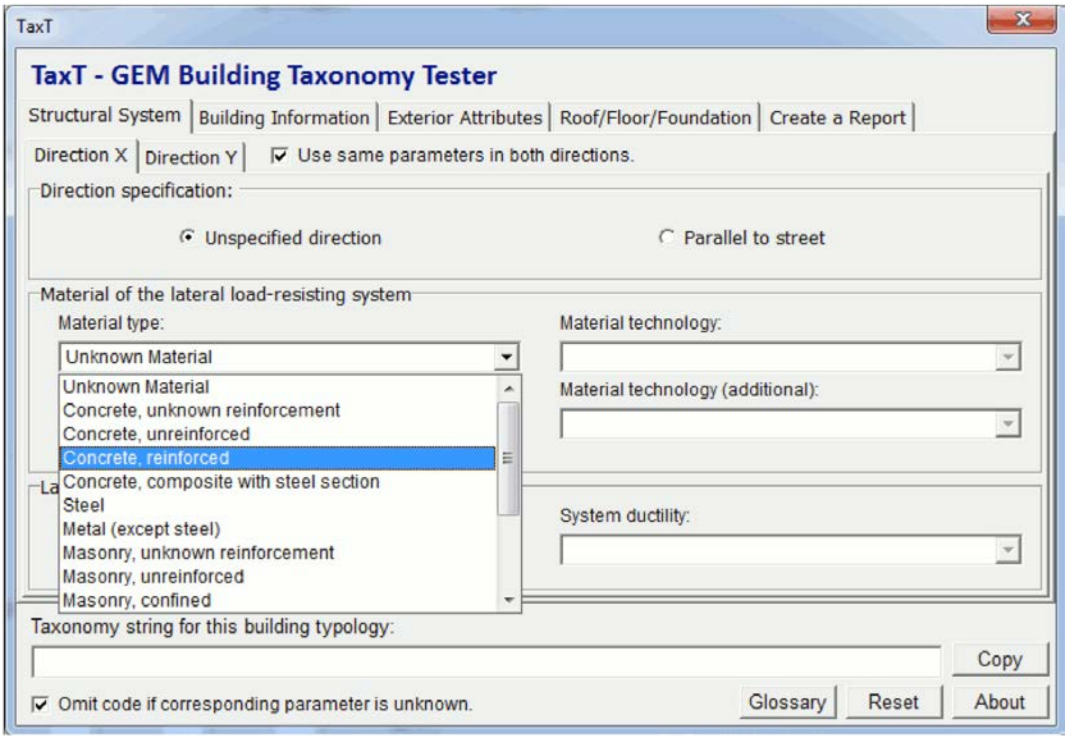


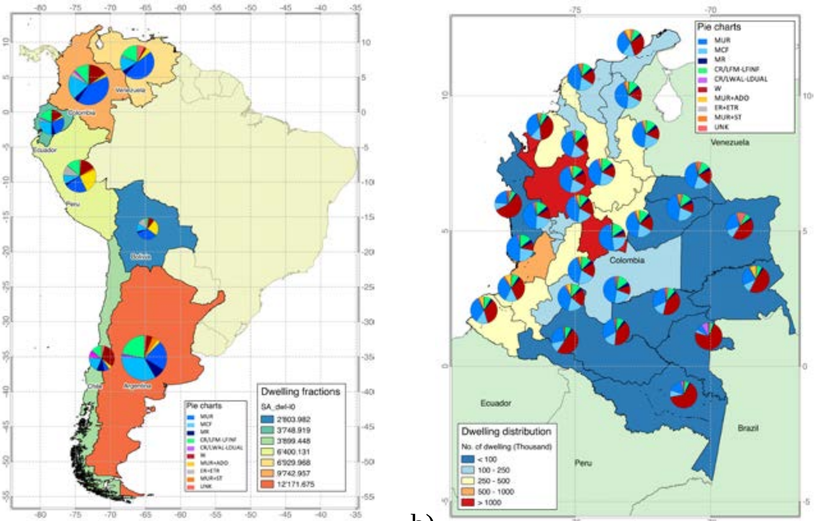
Figure 4. A screenshot of the TaxT tool.

6 EVALUATION AND TESTING

The GEM Building Taxonomy was independently evaluated and tested by the Earthquake Engineering Research Institute (EERI), which received 217 TaxT reports from 49 countries, representing a wide range of building typologies, including single and multi-storey buildings, reinforced and unreinforced masonry, confined masonry, concrete, steel, wood, and earthen buildings used for residential, commercial, industrial and educational occupancy. Based on these submissions and other feedback, the EERI team validated that the GEM Building Taxonomy is highly functional, robust and able to describe different buildings around the world.

7 APPLICATION OF THE GEM BUILDING TAXONOMY

The GEM Building Taxonomy has been widely used in many initiatives, such as national seismic risk assessments; development of regional exposure models; cataloguing of buildings for post-earthquake reconnaissance missions; and more recently, the classification of building portfolios for the commercial sector (insurance and re-insurance industry). Amongst these examples, it is relevant to further describe the case of the South American Risk Assessment (SARA) project. This initiative sponsored by the SwissRe Foundation aims to evaluate seismic hazard and risk for the entire continent, which inevitably requires the availability of a regional exposure model. In collaboration with tens of local experts, GEM has classified the most common building classes of each country, and used several sources of information to create a preliminary exposure model, as illustrated in Figure 5.



a) b)

Figure 5 – a) Distribution of dwellings per construction material for the Andean countries, b) distribution of dwellings per construction material at the first administrative level for Colombia.

Due to the use of this uniform classification system, it was possible to understand which were the most common building classes across South America, and thus where the efforts in developing new physical vulnerability functions should be focused. Moreover, these classification schemes were provided to local institutions responsible for the development of risk mitigation strategies, such as the implementation of structural retrofitting interventions.

Finally, it is also important to mention the role of this Building Taxonomy in the many workshops and courses supported by GEM every year, in places like Pavia (Italy), Lima (Peru), Bishkek (Kyrgyzstan), Istanbul (Turkey), Kathmandu (Nepal) or Potsdam (Germany). During these events, participants from various countries have the opportunity to classify the most common building classes from their region, and produce TaxT reports. This information is then made available to the wider community, or used to create more comprehensive reports, in collaboration with the World Housing Encyclopaedia initiative (www.world-housing.net). These actions are contributing effectively towards improving our understanding of the different types of construction in the whole world.

8 REFERENCES

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