# Building Inventory Data Development for Pre-Earthquake Evaluation

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**Abstract**

*The detailed building inventory data is needed for the pre-earthquake evaluation of urban areas. Unfortunately, this kind of data set is not sufficiently available in developing countries. Therefore, the Inventory Data Capture Tools (IDCT) developed by The Global Earthquake Model (GEM) Foundation was applied for building inventory data collection based on the field survey to sample buildings. The IDCT tools were developed for mobile and tablet type hardware, and also in the paper form for building data collection. These tools are designed to apply directly the GEM building taxonomy, allowing users to collect information using drop-down forms and pre-loaded options for all building attributes to be systematically collected. The IDCT is compatible with any GIS software and Google Earth Application. The Spatial Inventory Data Developer (SIDD) is important for creating "mapping schemes" – statistically generating of sampled building data distributions to areas of urban land use zones. These tools were successfully applied as a case study for Karakol city in Kyrgyzstan.*

## 1. Introduction

Kyrgyzstan, one of the developing countries of interest here, belongs to one of the most seismically hazardous areas in Central Asia. It is a mountain country and therefore many urban areas are located in areas that are endangered by different natural disasters, such as an earthquake, flooding and landslides. Earthquake is the most dangerous hazard that lasts a few milliseconds to a few minutes causing an immense destruction of buildings, infrastructure, loss of property and life. This hazard is sudden and also triggering secondary events such as flooding, landslides, avalanches and mudslides (UNISDR, 2009). The impact of the earthquake event is most distressing because it distresses larger area. Often, the damage of infrastructure is due to the used construction methodologies and lack of public awareness. The earthquake cannot be avoided, but there are ways to improve safety, minimize loss and injury, and increase public awareness. Urbanization with over population density and construction quality of buildings are now increasing the vulnerability of citizens of the city against earthquakes. To address this issue, earthquake vulnerability assessment is a useful approach, which provides a new basis for urban planning.

Pre-earthquake evaluation of urban settlement area is important not only to estimate the losses from future seismic events but also to make recommendations for prevention and preparedness (Dutta and Serker, 2005). The building inventory datasets are necessary for urban areas for pre-earthquake evaluation and this kind of inventory data is usually created through field surveys or visual interpretation using aerial photographs and high-resolution satellite images (Matsuoka et al., 2013). Mostly these methods are considered as costly and time-consuming (Dutta and Serker, 2005 and Matsuoka et al., 2013). But the acquisition of detailed land use information and building structural characteristics is required to combined use of satellite imagery with very high spatial resolutions. Land use information and characterization of building types are important for earthquake vulnerability analysis as well. In most developed countries, building inventory data is provided for pre-earthquake evaluation by local institutions and governments. However, the rapid urban growth is often accompanied by unplanned settlements in developing countries that rapidly change urban areas over short periods.

The building inventory data is essential for all types of natural disaster hazard and risk analysis (Dutta and Serker, 2005). There is no reliable source and developed database of building inventory in Kyrgyzstan. Recently, Department of Cadastre and

Registration of Rights to Immovable Property of the Kyrgyz State Registry Service under the Government of the Kyrgyz Republic has launched a national project "Registration of Addresses". It is mostly focused on the cadastral planning and immovable property data. The spatial data for the project have been collected for different periods over the country, but many regional offices do hot have datasets updated regularly. The complete cadastral data is expected to be developed within this project until the end of the year 2017. According to the preliminary data analysis, most of buildings are not digitized, structural categories and classification of the buildings types are missing. The mutual project cooperation is agreed between the Kyrgyz State University of Construction, Transport and Architecture (KSUCTA) and state agencies for further data exchange and share of practical experiences in the field of database management.

The main objective of this study is investigations and application of the Inventory Data Capture Tools (IDCT) and very high spatial resolution (VHSR) satellite imagery for the development of the building inventory data based on field survey as well as the spatial analysis of urban areas for the purpose of disaster risk assessment.

## 2. Inventory Data Capture Tools

The Global Earthquake Model (GEM) Foundation is an international public-private partnership to develop open-source software and tools for global seismic risk assessment and management (Bevington et al., 2011). The direct observations are developed by the GEM's Inventory Data Capture Tools (IDCT) consortium for direct capture inventory on pre-earthquake, as well as post-earthquake damage data collection (Bevington et al., 2012). These tools include both digital and paper forms for building data collection from field surveys (Figure 1). The Mobile Tools are the digital data collection applications that run on Windows (Jordan et al., 2014) and also designed to run on Android (Rosser et al., 2013) operating systems (OS). These tools are designed to systematically collect all attributes of building information using drop-down options and pre-loaded forms. It also includes metadata on location, surveyor details, date, time and additional information. The Windows Mobile Tool supports any raster and vector data formats and is especially useful during the field survey when a GPS device is connected (Jordan et al., 2014). The Android Mobile Tool supports tile mapping systems defined by the Open Street Map (OSM) and Google tile indexing, and also requirements for vector data is in KML format. The Android tool has advantage for automatically link of directly taken photographs to individual survey records (Rosser et al., 2013), while Windows tool is not due to the absence of suitable camera but it is also could be done by their description in the database to link photograph files from camera after the field work (Jordan et al., 2014). Paper forms also contain the same information as in the digital forms and the data table fields exactly match in the digital tools. The collected data on paper form will be manually added to the Windows tool. Both digital tools and paper forms are based on GEM Building Taxonomy (Jordan et al., 2014).

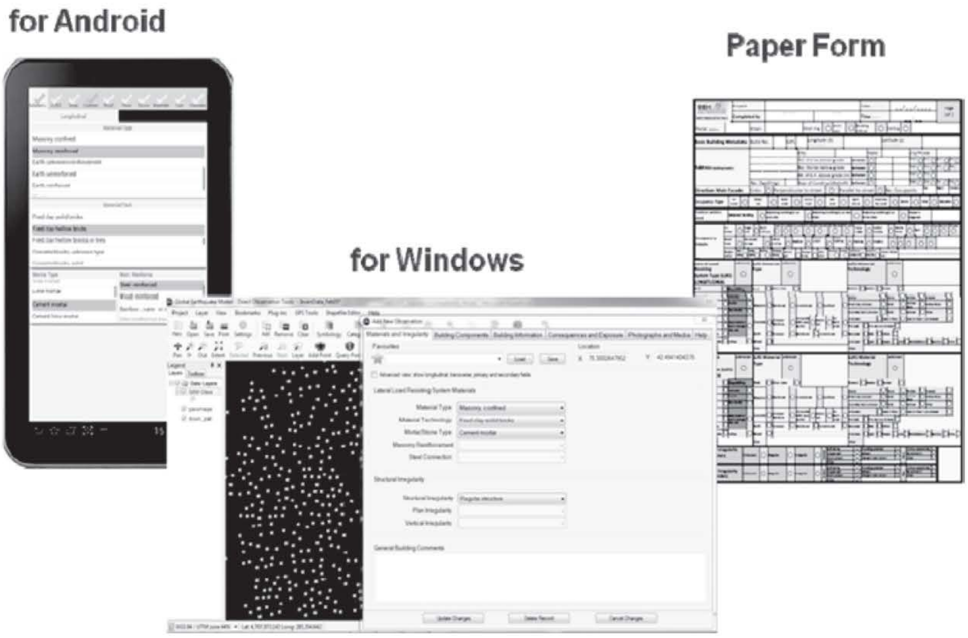


Figure 1. Inventory data capture tools

Table 1: GEM Building Taxonomy

| N | Attribute | Description |
|---|---|---|
| 1 | Direction | describes the orientation of building plan |
| 2 | Material of the lateral load-resisting system | this attribute describes the material type of the building structure that resist lateral loads, and detailed information on the material technology as well as types of properties |
| 3 | Lateral load-resisting system | defines a type of the lateral load-resisting system and system ductility depending on its probable seismic performance before an earthquake |
| 4 | Height | building height describes the number of storeys above the ground; and if exist below ground information it also will be included in the attributes |
| 5 | Date of construction | identifies the construction completed year of the building |
| 6 | Occupancy | the main type of functionality of the building that describes by various occupancies |
| 7 | Building position within a block | characterizes the position of a building to neighboring buildings which could be adjoined on one/two sides or detached |
| 8 | Shape of the building plan | building footprint shape, Square shape, H-shape, etc. |
| 9 | Structural irregularity | identifies of building's structural arrangement such as built in Regular structure; or Irregular structure which has a change of building shape in horizontal and vertical irregularity. |
| 10 | Exterior walls | used material of exterior walls, Masonry, Metal, etc. |
| 11 | Roof | specifies the roof shape, material and structural system supporting of the roof covering, and roof-wall connection. |
| 12 | Floor | classifies the floor material, structural system type, and floor-wall connection |
| 13 | Foundation system | the base part of the building, where foundation system depends on soil conditions, which characterizes as a shallow or deep foundation. |

## 3. Building Taxonomy

The GEM Building Taxonomy developed is to create a unique description and classification of buildings for seismic risk assessment. It is organized as a series of expandable tables, which include information referring to a variety of building attributes. Each attribute describes a detailed characteristic of an individual building that could potentially have an effect on seismic performance. Presently, the GEM Building Taxonomy Version 2.0 describes a building through the following 13 attributes (Brzev et al., 2013) that are tabulated in below Table 1.

Except for GEM Building Taxonomy, there are several existing taxonomies that mostly developed within the earthquake-related projects. Most of them focus on regional or country and global level of a building stock. For instance: The World Housing Encyclopedia (WHE) database includes architectural, socio-economic, vulnerability, insurance and also structural information about a building including photographs for each building type (www.world-housing.net); The US Federal Emergency Management Agency (FEMA-154) is focused to US-construction and consists of 15 building structure types (FEMA, 1988); Recently, by the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) system is extended to a global seismic building classification (Jaiswal and Wald, 2008); For European buildings is developed within the SYNER-G (2011) and another one the European Macroseismic Scale (EMS-98) that consist only 15 building structure types (Grünthal, 1998) . The GEM Building Taxonomy has been evaluated and tested in many countries including Kyrgyzstan (Fousler-Piggott et al., 2013). It was validated as highly functional and able to describe different buildings around the world (Brzev et al., 2013). The GEM Building Taxonomy is mostly used in computer-based applications and its detailed description is defined in drop-down menus in the database, where generates a building taxonomy strings. It is constructed for individual building with "/" slash symbols for separating each category of attributes. For example, the building in the Figure 2 will have the next GEM Building Taxonomy after observation:

**DX+PF(1) / ER+ERO(2) /LWAL+DUC(3) / HEX:1+HEX:1(4) /YPRE:1900(5) /RES+RES3(6) / BP1(7) /PLFL(8) /IRRE(9) /EWE(10) /RSH8+RMT2+RWO+RWO1+RTD99(11) /FW+FW2+FWCP(12)/FOSDL(13)**

This taxonomy string can be read as:
**(1) Direction** = [Direction X is parallel to street];
**(2) Material** = [Material type: Earth Reinforced, Material Technology: Earth technology, other]; **(3) Lateral Load-Resisting System** = [LLRS: Wall, System Ductility: Ductile];
**(4) Height** = [Number story above ground: Exactly 1, Number story below ground: Exactly 1]; **(5) Date of construction** = [Pre-1900];
**(6) Occupancy** = [Residential, Occupancy Detailed: Temporary lodging];
**(7) Building Position** =[Adjoining building on one side];
**(8) Shape of building plan** = [L-shape];

**(9) Structural irregularity** = [Regular];
**(10) Exterior walls** = [Earth];
**(11) Roof** = [Shape: complex regular, Roof covering: Fibre cement or metal tile, Roof system material: Wood, Roof system type: Wooden structure with light roof covering, Roof connection: Roof tie-down unknown];
**(12) Floor** = [Floor system material: Wood, Floor system type: Wooden beams or trusses and joists supporting heavy flooring, Floor connection: Present];
**(13) Foundation** = [Deep foundation with lateral capacity].

## 4. Mapping Scheme

Mapping schemes are the IDCT tool for building inventory data generation using the Spatial Inventory and Damage Data (SIDD) tool (Hu et al., 2014). It is a desktop-based workbench for data loading, editing and creating mapping scheme, which represents a statistical summary of sampled buildings in each category of homogenous land use zones by the Building GEM taxonomy (Bevington et al., 2012). Mapping schemes refer to allocating the distribution a number of buildings by detailed structure type, occupancy, and number of stories, or any number of "branches" defined by the user.

## 5. Field Survey

Building Inventory Data development is based on the field survey carried out in May 2015, as case study area for Karakol city, Kyrgyzstan. Undergraduate students of the Applied Geodesy Program (group PG-1-11), Geodesy and Geoinformatics Department of the Kyrgyz State University of Construction, Transport and Architecture (KSUCTA) are participated in the filed survey. These students have basic knowledge on Building Architecture, Building Structures, Construction Technology and Geodetic Surveys. This survey was coordinated and led by the university researchers and realized during two field surveys in the study area.

The WorldView - 2 image with the panchromatic spatial resolution of 0.5 meter and multispectral images (blue, green, red and near IR band) with spatial resolution of 2 meters (October 12, 2011) is used as a base map for the survey and data integration. This remote sensing product was provided within the project of the Consortium for Seismic Risk Analysis in Central Asia (COSERICA) coordinated by the German Research Centre for Geosciences (GFZ). Multispectral bands were fused to produce pan-sharpened multispectral images with 0.5-meter resolution. The resulting image perfectly represents spatial objects in details covering the study area. Preliminary, the available building footprints data were downloaded from the Open Street Map and other remaining data were manually digitized using World View – II satellite data by the survey team. In totally 11380 building footprints has been prepared for the survey. According to the architectural planning and cadastral mapping information, where Karakol city is officially divided into four zones. Each zone contains several blocks which have a unique identification code number. It is counted more than 400 blocks over the city. For our purposes this number is big, and therefore jointly with city cartographer was delineated homogenous urban zones and assigned codes (Figure 2). For instance: the used code - Z1B1, means Zone 1 and Block 1; while OS means open spaces that contain non-built-up areas. By the survey team were observed around 2500 buildings and more than 500 photographs of buildings were collected. The captured photographs are the invaluable data source that serves to describe many parameters of a building such as geo-location coordinates, look direction, structural characteristics, storey numbers, data and time information, and etc. The distribution number of building footprints and observed buildings within homogenous zones are shown in Figure 3.

The field survey was carried out by visual inspection of buildings without entering into a building and sometimes was asked from man-owners about the engineering structural characteristics of buildings such as day-time mostly women and children stays at the house. By walking along the street was visually observed and collected building structural information. The IDCT-Mobile tools, paper forms, GPS devices and digital cameras were used for the building inventory data development. These tools were very helpful to define physical vulnerability indicators of buildings that could not be derived from satellite images, such as building structural material type, occupancy, year of construction, roof type and lateral-load resisting system.

During a field survey, by use Mobile tools were created the several Favorite lists that specify various building types. Each list was saved with a different name after observation of building that stores the same information of building types. Every time before start collecting data at another location simply was selected the corresponding list name from the Favorite menu and the relevant fields of information were automatically completed. It is a time-saving device that can be automatically added the saved entire building attributes to a new survey of a building.

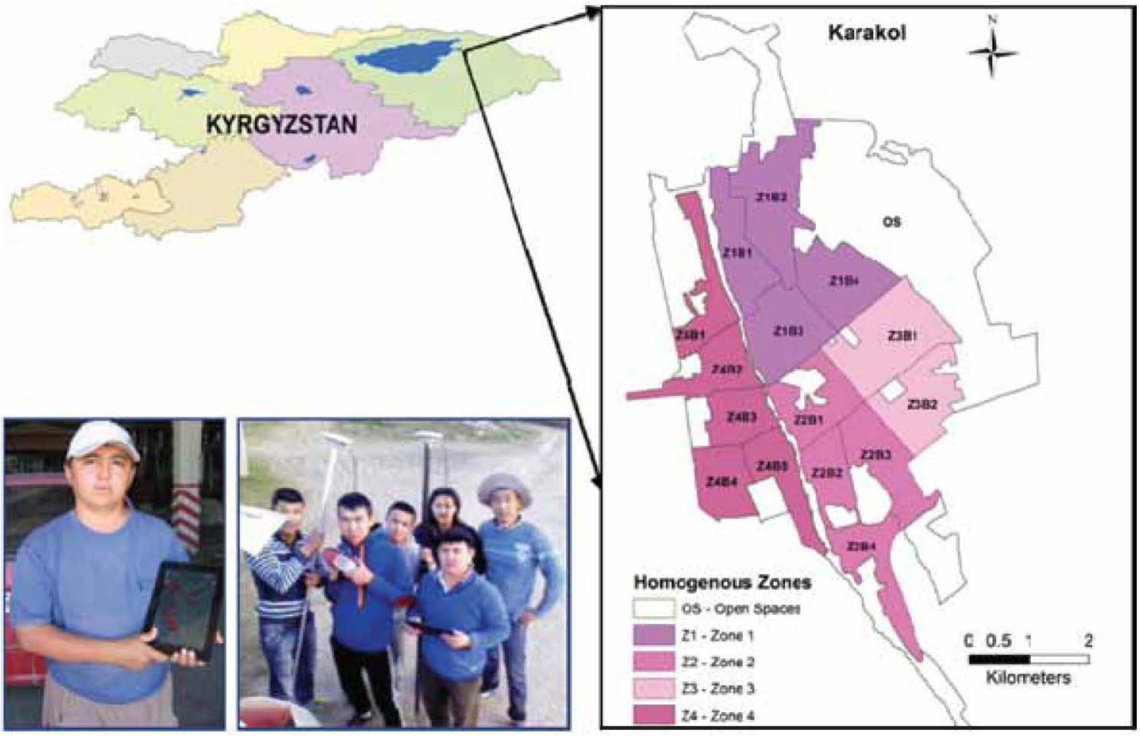


Figure 2: Study area and survey team, Karakol city, Kyrgyzstan

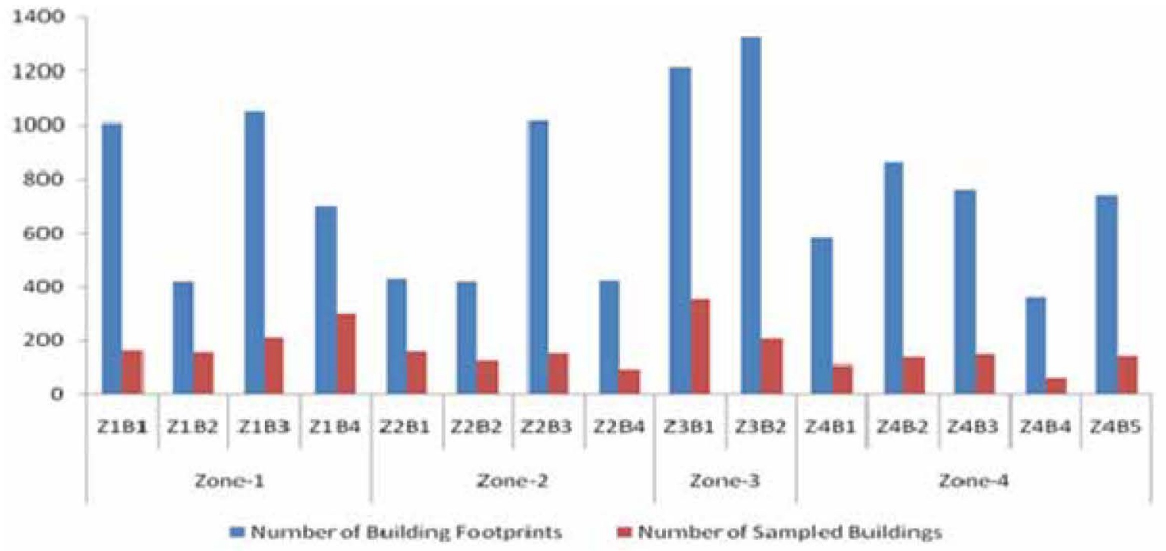


Figure 3: The distribution number of buildings

**6. Building Distribution Analysis**

Using the Spatial Inventory Data Developer (SIDD), two times buildings data distributions were generated, one based on the single city level, and the second based on a homogeneous urban block level. Figure 4, shows the hierarchical distribution of buildings data by "Occupancy" and "Material" over the city. Here occupies with the highest percentage is Residential buildings (RES) - 78,2% and lowest one is Agricultural (AGR) – 0.1%. The majority of used construction materials for Residential buildings are Masonry Reinforced (MR) - 31.2% and Masonry Confined (MCF)-24.7%. The Agricultural buildings shares by 50% of the Earth Reinforced (ER) and Masonry Unreinforced (MUR) types.

The generated of buildings data distribution in homogeneous zones level are shown in Figure 5. For this purpose were included three types of data: “Material”, “Occupancy”, and “Height”. A Map in the left side represents the majority of building taxonomy within homogeneous urban zones. For instance, the generated taxonomy “CR+CT99/RES/HEX:5” will be described as Concrete reinforced building with unknown Concrete technology and Residential purposes with the exact 5 storey numbers. The right side graph is illustrating a statistical distribution of building taxonomy within individual urban zones. Here, as an example is shown for two blocks of urban Zones-1, Z1B1 and Z1B2.

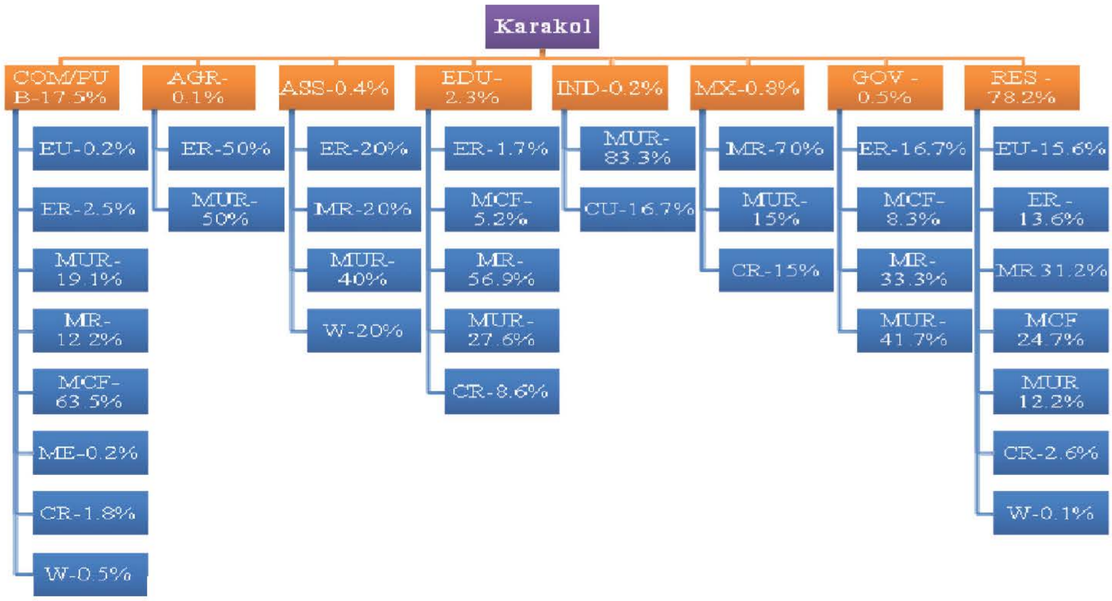


Figure 4: The distribution number of buildings

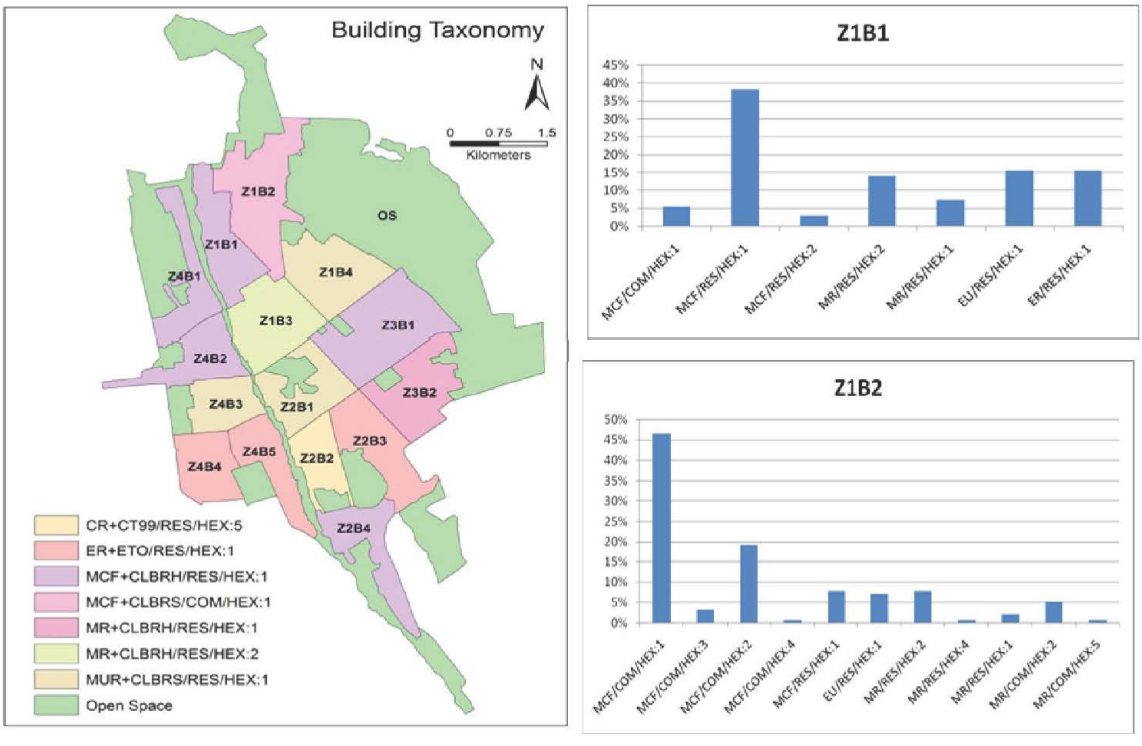


Figure 5. Buildings data distribution within homogeneous zones

## 7. Conclusion

The combined application of satellite imageries and use the Inventory Data Capture Tools (IDCT) for building inventory data development is the main purpose of this research work. The available IDCT open source tools were used for the field studies. These tools have user-friendly interfaces with tabbed-functionality that allows convenient and easy field data collection according to the international GEM taxonomy. The building inventory data collection is requiring of the detailed field observations of buildings in urban areas, but it can be costly for a full inventory characterization over large areas. Emerging crowdsourcing methods together with local engineers and students participations were an invaluable support in the inventory development process. The provided local expertise information has improved the quality of data collected.

The developed building inventory data is essential for pre-earthquake and disaster risk analysis, which provides useful information for decision making against earthquake events. Further, the collected inventory datasets will be applied in exposure estimation and vulnerability assessment of buildings.

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