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Technical paper

Building exposure model for seismic risk assessment of the city of Strumica

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ABSTRACT

Seismic risk assessment at the city scale has always been useful for pre-earthquake planning, managing future investments, and prioritizing the seismic repair and retrofit of existing buildings immediately after the earthquake. It is carried out by combining hazard, exposure, and vulnerability models. Exposure in this context, refers to the elements at risk: population, buildings, lifeline systems, or socio-economic activities. Risk assessment analysis for different regions and cities worldwide shows that exposure and vulnerability are key elements for effective risk assessment.
This paper provides an inside into the development of an exposure model of Strumica, North Macedonia, that describes the distribution of Strumica's main residential, industrial, and commercial building classes. The exposure database consisting of the existing building inventory is created using the international standard taxonomy for earthquake risk assessment, proposed by the Global Earthquake Model.
This exposure model points out problems and concerns brought about by the implementation process and details the practical solutions and strategies used to achieve the set goals.
The long-term expectation is that this exposure model will allow updating existing plans for emergencies, crises, and disasters, allowing city planners to include seismic risk assessment analyses that contain real data to encourage future risk reduction strategies.

1 Introduction

Over half of the world's population lives in high-risk areas exposed to at least one type of natural hazard: floods, cyclones, droughts, or earthquakes. Earthquakes are one of the most devastating and terrifying natural disasters that a human being can experience, and they can cause almost two-thirds of total annual world economic losses [1].

Seismic risk assessment can be defined as a process that determines the probability of losses by analyzing potential hazards and evaluating existing vulnerability conditions that could threaten or harm people, properties, and the environment on which they depend [2], [3].

The assessment of seismic vulnerability as one of the primary components of risk depends on the characteristics of the buildings or group of buildings being analyzed and the available information about them, the appropriate assessment method (qualitative or quantitative), and the field data collected.

Identifying relevant parameters of the exposed building stock is the first step in establishing a rational basis for creating risk reduction strategies and providing a realistic estimation of seismic vulnerability [4].

Data on social and economic losses from past earthquakes show that the most frequent and greatest losses are those caused by damage and collapse of buildings [1]. Precisely because of this, the data on the existing building stock must be adequately evaluated and updated promptly. An assessment of damage and losses to existing building stock cannot be done without first creating an exposure model that contains all the necessary information about the buildings that are the subject of assessment.

The exposure model is a key component of a seismic risk model, which captures the spatial distribution of population and built assets along with their structural characteristics and valuation that are required for seismic risk assessment [5].

This study describes the development of a building exposure model for the City of Strumica [6] containing information on geographical distributions, structural characteristics, age, number of stories above ground, ductility of building structures, structural cost for each building, and building occupancy. Existing available data

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which includes 4367 buildings, have been updated to create the most relevant building exposure database possible.

2. Study area

2.1 Seismicity

The territory of the Republic of North Macedonia and the bordering countries (Albania, Bulgaria, Greece, Serbia-South) are among the most seismically active regions of the Balkan Penisula. Historically, these territories have been affected by several moderate, strong, and major earthquakes associated with damaging intensities reaching IX to X degrees of MSK-64 seismic intensity scale [7]. According to the existing historical records, many destructive earthquakes struck the territory of Macedonia and its adjacent regions, before 1900.

Strumica is a city in the Southeastern region of the Republic of North Macedonia [6], where tectonic activity is less pronounced [8]. It belongs to the Valandovo-Gevgelija Seismotectonic Zone out of 10 Active Seismotectonic Zones determined from consideration of the present-day SBER tectonic regime of the region and the subset of the Macedonian earthquake catalog [9]. Along the Strumica fault which is very traceable in the relief and limits the graben from the Belasica horst, occur rare and weak earthquakes [7]. The strongest earthquakes that affected the Strumica region took place in 1904 (Pehchevo-Kresna Mw.7.2) [10] and 1931 (Valandovo-Dojran Mw.6.7) [11].

Relatively weak earthquake activity in the Strumica city area should not be a reason to underestimate seismic risks. Even if future studies for the city prove that seismic risk due to local seismicity can be neglected compared to some other risks for the existing building stock, recent studies have shown that the closeness of the Valandovo area as the seismically most active area in that region [7] can influence the behavior of the buildings in case of stronger earthquakes.

2.2 Seismic exposure

The uneven distribution of the population and rural-urban migration are important demographic characteristics not only in North Macedonia but in all European countries nowadays. According to the data available, following the Detailed urban plan of the city of Strumica, for which a general urban plan was also adopted, the city itself covers a total area of around 529,41 ha.

According to the Housing and Population Census of the Macedonian Statistical Office in 2021, the population of the city of Strumica is 49,995 thousand inhabitants, of which 33,825 thousand are urban and 16,170 thousand rural, with a total number of 17,400 households located in the city [12]. The size of the city and its population make it one of the largest cities in the southeast of the country.

The available census data are only partially useful because, apart from the housing and population data, they contain no data about the structural characteristics of the existing building stock in the city (material, load-resisting system, number of floors above ground).

The assessment of exposure and damage to the building stock in the city of Strumica, in this paper is based on original data (geographical coordinates, gross and net floor area, and height of the buildings) taken from the Agency for Real Estate Cadastre of North Macedonia [13] and field observations made by the authors and local experts with relevant experience and knowledge in the field of research, to determine the structural system, year/period of construction of the buildings, and/or ductility of building structures.

To obtain a more reliable exposure model of the city of Strumica, it must contain the main structural characteristics of the existing building stock, as the most important data. Only relevant data in the exposure model applied can create relevant risk assessment analysis contributing to reducing negative effects on buildings and people's health and life during and after an earthquake happened.

3. Exposure model for the city of Strumica

3.1 Development of an exposure model

The exposure model intends to collect building-level data only for certain, valuable attributes that are related to specific typologies of buildings and allow risk calculations for each examined building [1]. For the exposure model for the city of Strumica, a working methodology is elaborated, which started the whole process of building exposure modeling by first providing an orthogonal photo of the city of Strumica taken by authorized Geodetic work companies located in Strumica. After obtaining the orthogonal photo of the city it was processed with the help of photogrammetric recording carried out by licensed and authorized geodetic engineers, during which a model of the terrain was obtained, where with the help of special parameters for our country, this model was brought to the exact position according to x and y coordinates and georeferenced rasters were obtained for the city of Strumica. The obtained georeferenced rasters for the city are adopted and applicable by the Real Estate Cadastre Agency of Macedonia [13] Fig.1 (right). These georeferenced rasters for the city of Strumica represent a base on which the existing buildings at the city level proceeded.

All the information about the analyzed building stock, which consists of a total of 4367 objects (Fig. 1 right), was obtained through the process of vectorization and attribution of the real estate (buildings) performed in two software platforms (CAD and GIS): the graphic display of the objects is carried out in the AutoCAD software, while the attribute data for the objects (gross and net floor area, number of buildings, its dimensions and height) were processed in the QGIS software tool [14], based on data previously taken from The official web portal of the Real Estate Cadastre Agency of Macedonia [13] and from the authorized offices of the Real Estate Cadastre Agency of Macedonia located in Strumica.

The structural characteristics of the existing building stock, including 4367 buildings, were collected in situ. The structural system of the buildings was determined through the evaluation of field inspectors based on their experience/knowledge while for determining the year/period of construction, interviews were conducted and questionnaires were distributed which were duly filled by the local citizens living/working in the buildings which were subject to analysis. After collecting the data, it was initially recorded on paper forms, and then transferred to Excel spreadsheets. To continue the procedure, the existing Excel file was converted into a so-called CSV (comma-separated values file) which contains attribute data and coordinates that are closely related to the geometry of the objects in question. It was this file that was imported into the QGIS software tool [14], a tool through which we graphically displayed the obtained results.

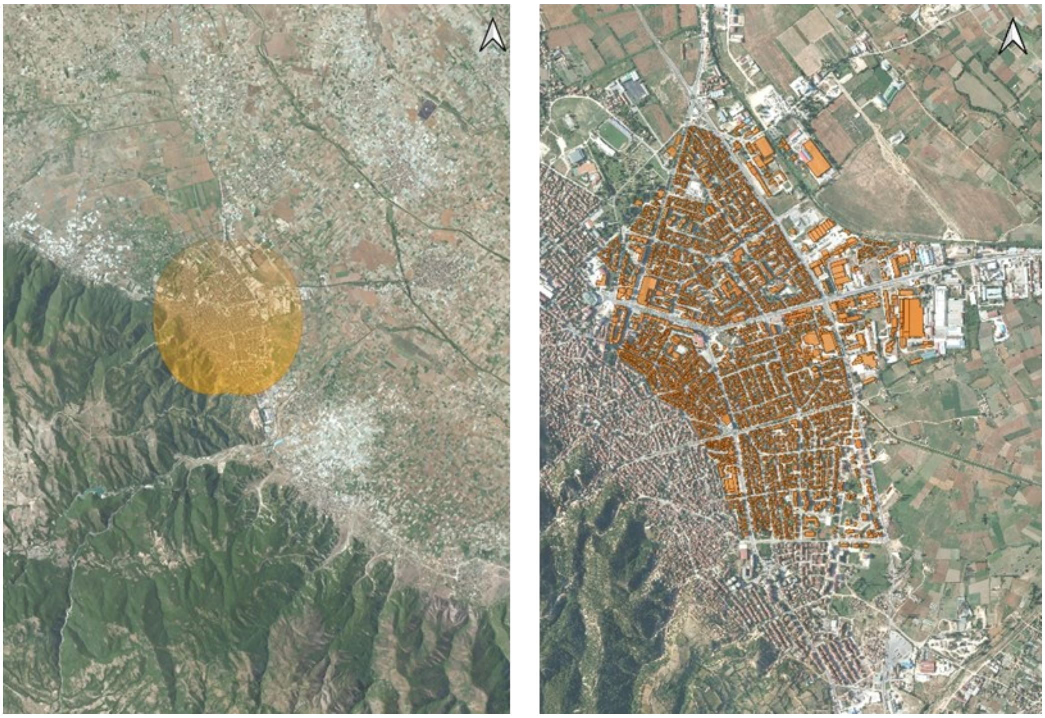

Figure 1. Location layout (left) and existing building stock in the city of Strumica (right) graphically processed in OGIS software tool

After the basic database for the city's exposure model was formed, building classification using the GEM building taxonomy was done. The attribute data such as the building taxonomy was entered and completed by automation in the selected software.

3.2 Classification of the existing building stock using gem building taxonomy

Records of past earthquakes and numerous scientific studies show that some building features have a greater impact on a building's earthquake resistance than others. The building material (brick, reinforced concrete, steel, etc.) and the lateral load-resisting system of the building are very important features that largely define the behavior of buildings during and after an earthquake.

Each material has a different behavior during and after an earthquake. For example, reinforced concrete buildings and steel frame buildings have shown very good behavior during past earthquakes, compared to unreinforced masonry constructions that have shown the worst behavior causing a huge number of losses (human and economic) during earthquakes that occurred in the past [15]. To assess the behavior of buildings in post-earthquake conditions, it is necessary to systematize the existing building stock and provide information on the number of residential, commercial, and industrial buildings and the number of its residents even in the smallest administrative unit of a state-level, data contained in the city's exposure model.

In 2012, the Global Earthquake Model (GEM Building Taxonomy v2.0) adopted 13 attributes that create an exposure model that, alone or in synergy, can significantly affect the seismic behavior of the buildings [16]. In this paper, an exposure model of the city of Strumica, which contains a total of 4367 buildings located in the city, corresponding to the existing situation on the field, graphically presented in Fig. 1 (right) is created. The existing building stock in the city is classified into different building classes according to the building taxonomy scheme developed by GEM (GEM building taxonomy scheme) [16] according to four (4) attributes: main constructional material, number of floors above the ground, year of construction (seismic code), or ductility of the building structure (Table 1). Two more attributes such as the structural cost of each building and building occupancy are taken into consideration while developing the exposure model.

Taking into account the recommendations of the GEM Building typology [16], the available data sources, and the construction specificities in the urban area, the attributes that have been adopted to describe the analyzed buildings classified according to GEM are elaborated (Fig. 2,3,4,5) by:

a) information on the main constructional material used,
b) number of floors above ground level
c) year or period of construction of the building or
d) ductility of building structures

Information about the main construction material used was provided through a visual inspection on site involving field inspectors with previous experience/knowledge.

Data on the number of floors above ground are provided online through the official web portal of the Real Estate Cadastre Agency of Macedonia [13].

The year/period of construction was determined through conducted interviews with local citizens and questionnaires that were properly filled out by them and referred to the buildings in which they live or work and are defined as the main subject of our analysis.

The seismic code of the existing building stock in Strumica is determined considering the evolution of seismic design codes and construction practices in the Republic of North Macedonia (RNM), based on [17], where it is confirmed that three out of four categories of seismic design codes are present in our country: Absence of Seismic Design (CDN) for structures designed before 1948, Low Code Level (CDL) for structures designed between 1948 and 1964, and

Moderate Code Level (CDM) for structures designed from 1964 up to today.

Regarding the ductility of the building structure, for this paper, the European and Global Exposure Model experiences from [18], are applied, where it is confirmed that the ductility of each building structure directly depends on the year of construction and the development of the valid seismic codes and standards of aseismic design in the country/region/town that we are investigating.

In addition to the defined building taxonomy for the existing building stock in the city of (Tab. 1) and their number at a city level (Fig. 4) to more accurately assess the expected vulnerability of buildings from an earthquake, two other important attributes that should be included when completing the exposure data are the: structural cost of each building individually, which in this paper is obtained value using an Official template for determining the value of the building per m^2 prescribed in the Methodology for determining the value of the apartment (Official Gazette of the Republic of Macedonia 13/10) [19] and the building occupancy, an attribute that contains the exact number of users/occupants in each building at different periods of the day, day/night/transit, obtained using available information officially published by the State Statistical Office based on the 2021 North Macedonia, census region 14 - Strumica [20]. Building occupancy is a parameter that is usually used to estimate seismic risk in terms of the number of deaths or injuries after an earthquake happens.

Table 1. Structural typologies for the building's stock in the city of Strumica using the GEM Building Taxonomy scheme [16]

Material	Lateral load-resisting system	Ductility	Seismic Code	Height
MCF (Masonry)	LWAL (Wall)	DUL (Ductility Low)		H:1-H:3
MUR-STDRE (Unreinforced masonry, dressed stone)	LWAL (Wall)	DNO (Non Ductile)		H:2-H:3
MUR-ADO (Adobe Structures)	LWAL (Wall)	DNO (Non Ductile)		H:1
CR (Concrete)	LFINF (Infilled frame)		CDM (Moderate code)	H:1-H:5
CR (Concrete)	LDUAL (Dual frame)	DUM (Ductile, medium)		H:4-H:8
CR (Concrete)	LWAL (Wall)	DUM (Ductile, medium)		H:5
CR (Concrete)	LFM (Moment frame)	DUM (Ductile, medium)		H:1-H:5
S (Steel)	LFM (Moment frame)	DUM (Ductile, medium)		H:1-H:2
S (Steel)	LFBR (Braced frame)	DUM (Ductile, medium)		H:1

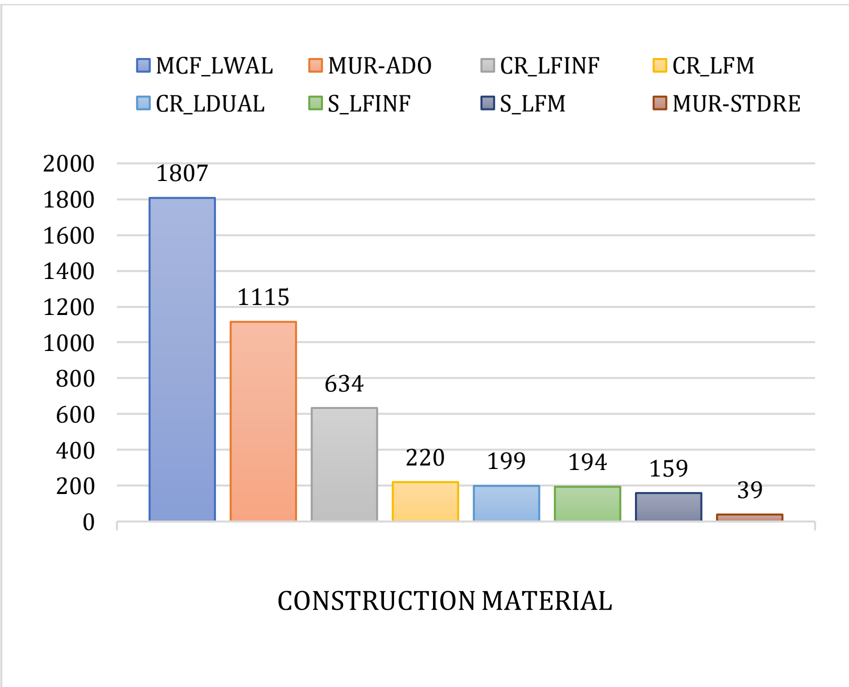

Figure 2. Number of buildings at Strumica city according to: construction material

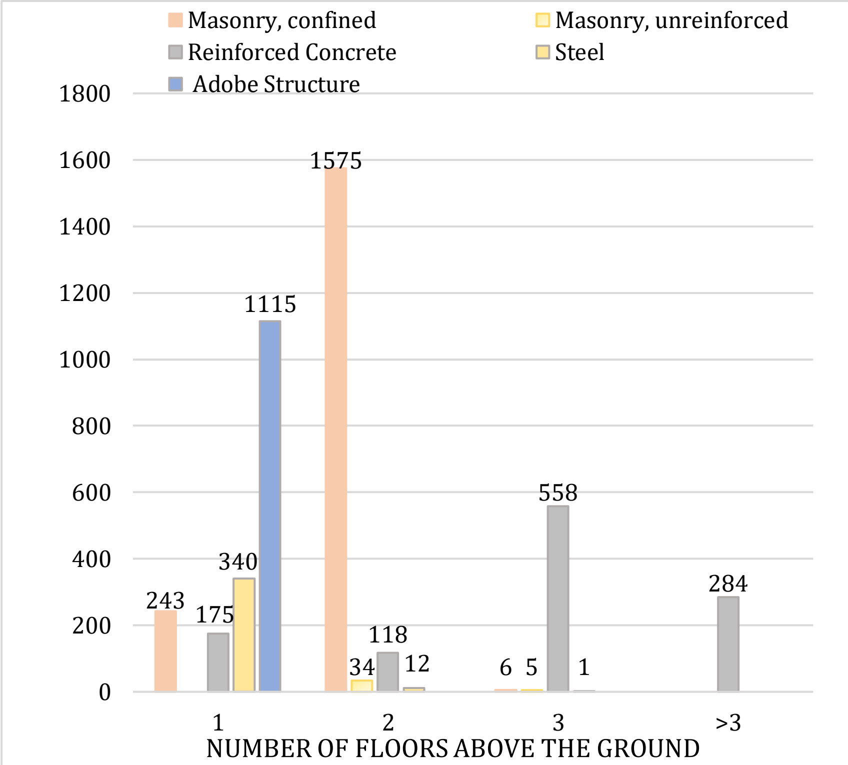

Figure 3. Number of buildings at Strumica city according to: the number of floors above the ground

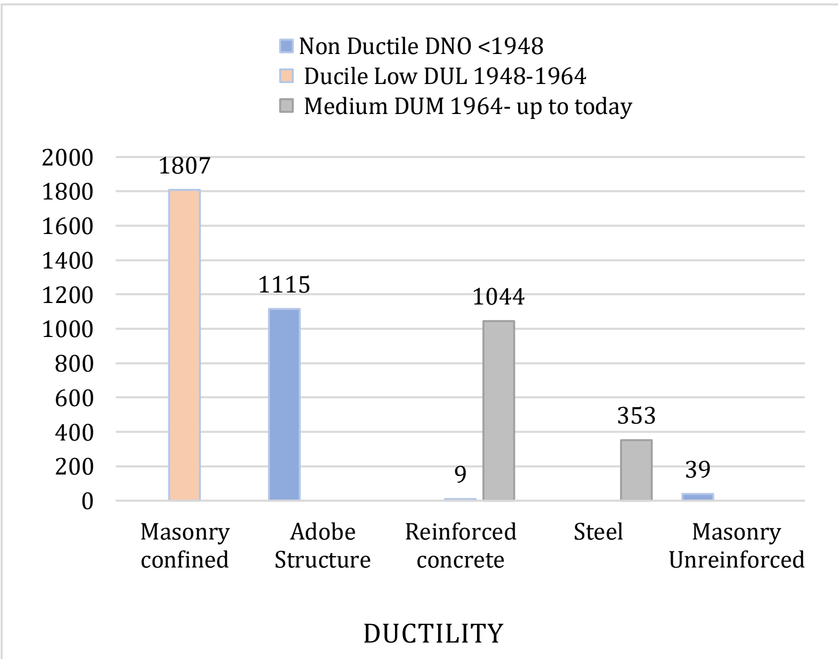

Figure 4. Number of buildings at Strumica city according to: ductility of building structures

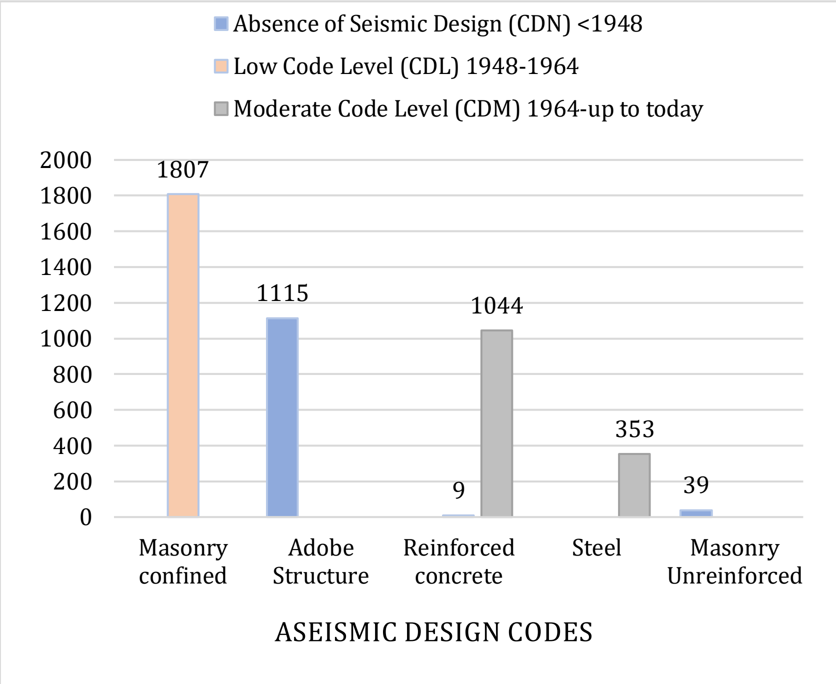

Figure 5. Number of buildings at Strumica city according to aseismic design codes

Although the detailed description of building attributes is of great importance when creating the most relevant exposure model, nowadays researchers tend to simplify building taxonomies when creating a city's exposure model to completely exclude incomplete and/or unreliable information in connection with the existing building stock. The obtained results for the building stock at a city level (4367 buildings) presented in Fig. 2 show that in terms of construction material, masonry confined buildings (MCF_LWAL) are the most common group of buildings represented with a total number of 1807 buildings. The second most common group of buildings in the city such as: garages, utility areas, and sheds known as adobe and earthen structures (MUR-ADO) are represented with a total of 1115 buildings.

Regarding the height of the buildings, the largest number of buildings at the city level:1575 buildings are two-floor masonry confined buildings (G+1) (Fig. 3).

Regarding the ductility of the buildings, most of the analyzed building structures at the city level:1807 buildings are low ductility structures (built in the period 1948-1964) (Fig. 4).

Regarding the period of construction of the buildings and the implementation of the codes for seismic design [17], [18] the largest number of buildings, or a total of 1807 buildings, were built in the period 1948-1964 (low code level) following the evolution of seismic design codes and construction practices in RNM, based on [17] (Fig. 5).

After defining the dominant building classes of the analyzed buildings at a city level, according to the building taxonomy scheme developed by GEM [16] (tab.1), The authors visually inspected buildings in the field. In tab. 2 photos/examples of typical buildings for the respective typology are shown.

Table 2. Building classes in Strumica City (current state)

		
MUR-ADO_LWAL-DNO_H1	**MUR-STDRE_LWAL-DNO_H2**	**MCF_LWAL-DUL_H3**

 **CR_LFINF-CDM_H2**	 **CR_LDUAL-DUM_H8**	 **CR_LFM-CDM_H4**
 **CR_LWAL-DUM_H5**	 **S_LFINF-DUM_H1**	 **S_LFM-DUM_H1**

3.3 Data processing and visualization from the strumica database

The ultimate goal of developing the exposure model for the city of Strumica is to make the collected data useful for planning and preventing earthquakes and other disasters simple, accessible for wider use, and timely updated. As the focal points in exposure modeling involve adding new data, changing, and harmonizing available existing data and its visualization, a computer open-source system Quantum GIS, a geographic information system (GIS) [21] is chosen as a system that can collect, store, analyze, and display geo-referenced data for the chosen city. The distribution of buildings in the city of Strumica, respecting the material, the load-resisting system of buildings, number of floors above ground are shown in Fig. 6 using QGIS.

4 Conclusion

The development and application of exposure models are of great importance to promptly predict and assess building damage and losses. In this paper, throughout the data collection stages, a large number of building attributes were observed and recorded, however, only simplified taxonomies that discard most of the important information about the existing building stock, are used. To examine the overall earthquake performance of buildings through earthquake risk assessment, this exposure model includes the following attributes: longitude and latitude and a building string that contains construction material, year/period of construction or ductility of building structures, and height of buildings above ground.

A three-step methodology was applied to develop an exposure model for the city of Strumica. In the first step, all the necessary building attributes are identified, collected institutionally or on the field, and finally synthesized into an integrated whole. In the second step, according to the adopted methodology for the classification of building typology developed by GEM [16], the existing building taxonomies at the city level are defined. The final third step is visualizing the obtained results using the geographic information system (QGIS) program [21]. Using this program, verified and reliable data on the built construction stock are graphically displayed and easily readable by the general public.

The purpose of this study is not to provide a detailed analysis of the existing building stock in the city because it is a long process that requires a series of additional research and numerous financial resources. This study represents an attempt to make an expert technical assessment of the building stock at a city level, which would greatly help decision-makers to take timely measures for the prevention and mitigation of the consequences of earthquakes as natural disasters. It should be promptly updated and further developed by the ones interested in risk assessment.

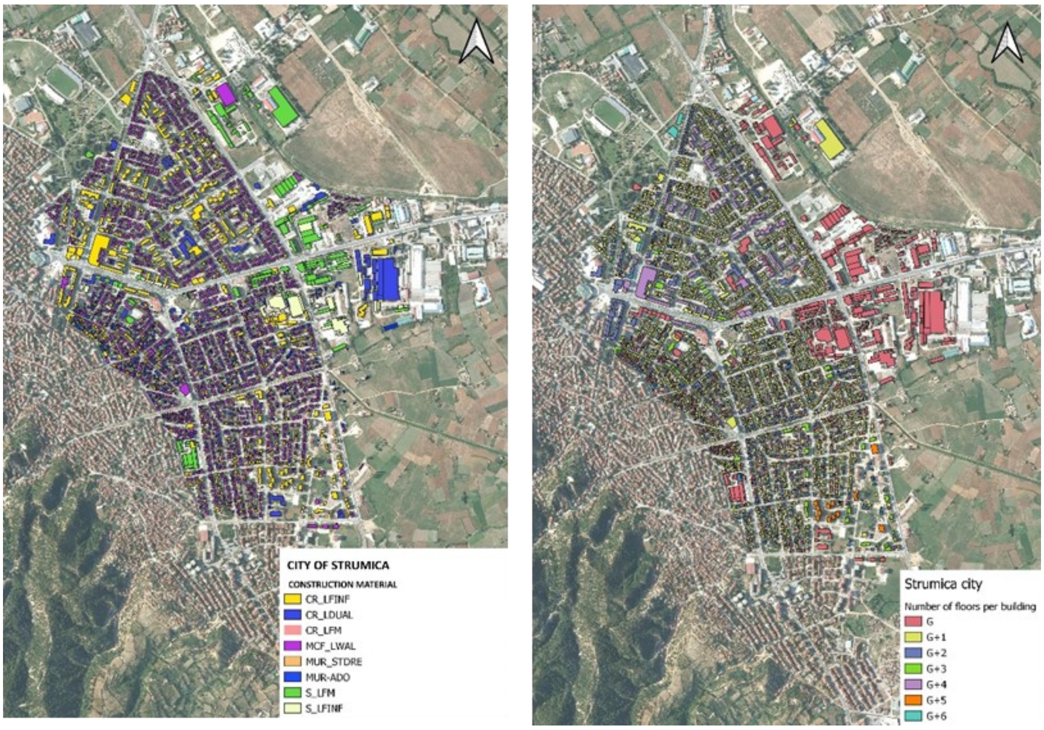

Figure 6. Strumica Database Buildings Using QGIS: a) construction material, b) number of floors above ground

Credit authorship contribution statement

Nadica Angova Kolevska: Data curation, Formal analysis, Investigation; Resources, Software, Visualization, Writing - original draft.

Marija Vitanova: Supervision, Validation, Writing - review & editing.

Nadica Angova Kolevska, Marija Vitanova: Conceptualization, Methodology, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article

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