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Integrating Cadastral Data with Seismic Risk Data in an Online Building Database for the Historical Centre of Bucharest City

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Abstract: The Historical Centre of Bucharest City is a highly populated area and a popular tourist attraction, known for its old buildings, some of which were built before the year 1900 and were severely damaged by the 7.4 magnitude earthquake in 1977. Seismic risk available data consist of lists published by the Municipal Administration for the Consolidation of Buildings with Seismic Risk, and include various information about the buildings for which technical expertise was conducted. Available cadastral data can provide additional information about the buildings, including the buildings' location and area. In this article, we aim to integrate the available cadastral data with seismic risk data in an online building database for the Historical Centre of Bucharest City. Such a database can be used for further 3D city modelling, which can be helpful in disaster management and emergency situations response planning. Previous initiatives in this regard did not provide precise geospatial data or important attributes regarding the situation of these buildings. It is vital to take into account the official data related to the property, mentioned in the National Land Registry.

Keywords: buildings; database; seismic; risk

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1. Introduction

Monitoring building stock can not only provide a better understanding of the energy performance of the building sector [1], but can also generate tools for disaster management through prompt response in emergency situations. Seismic risk assessment plays an important role in reducing the effects of the earthquakes in vulnerable regions [2]; therefore, a building database that includes information about the buildings' materials and seismic risk is necessary.

A building stock database can lay the groundwork for developing 3D city models, since the need for them is gradually increasing, as more and more benefits of using such models are being demonstrated. A 3D city model is a three-dimensional geometrical representation of urban objects and structures, with an emphasis on buildings, that can be used in numerous applications, such as visibility analysis, energy demand estimation, emergency response, shadow estimation, utility management, solar potential estimation, 3D cadastre, infrastructure planning, indoor navigation and noise propagation, synthesized in a study by Biljecki et al. [3]. The spatial data can be acquired through different methods that involve photogrammetry, laser scanning or GNSS technology, or can be derived from existing cadastral data, digital terrain models, 3D building models and architectural models [4].

A 3D city model based on a building database that includes seismic risk information and the building's materials, condition or renovation status can provide the tools for simulations that can model the possible outcome of an earthquake, as bricks or other pieces of the buildings are very likely to fall and cause damage during an earthquake. Buildings in such a condition are especially found in Bucharest's Historical Centre. Cadastral data can provide the exact location of the buildings, as well as the ownership situation, the number of floors, the building's area and other information that is relevant to this type of earthquake damage modelling. The purpose of integrating cadastral data and seismic risk data is to provide information such as the exact location and the renovation status of the buildings that may be potentially dangerous during and after an earthquake. This will improve the accuracy of earthquake damage estimation, emergency response planning and the strategy for financing building consolidation.

A semantic 3D city model is a 3D city model that integrates objects' attributes, such as usage, nature, etc., as well as certain relationships between these objects, like spatial relations, topological relations, etc. The semantic enrichment of a 3D city model is a process that involves adding new information to an existing model in order to better connect it to reality [5]. The newly added information could be from georeferenced Web sources, such as Wikipedia, Geonames, Open Street Map [6], existing GIS sources, urban master plans, databases with experience figures, financial data models, sustainability data and models [7].

Creating a building database can be an initial step in developing a 3D city model, as it can provide the right type of data to enrich the model and make it available for use in various fields of interest. In this regards, we analysed various 3D city models and building databases by their building attributes, in order to propose a list of attributes for a building database that can not only lay the groundwork for further 3D city model development, but also improve the accuracy of earthquake damage estimation and emergency response planning in Romania, a region that faces an intense seismic activity from the Vrancea region, with a huge impact on the capital, Bucharest, known for its old buildings, which were already severely damaged by the 1977 earthquake.

Numerous building databases already exist, but they mainly focus on energy demand and do not integrate seismic risk and cadastral data, which are vital for an accurate earthquake damage estimation. The necessity to integrate 3D data with seismic risk data in Romania was previously expressed by Lates and Crenganis [8], and is still an important issue. In the mentioned study, the importance of seismic risk data and information about the reparation and consolidation status is expressed, but no such data were collected and analysed. A GIS framework for seismic loss assessment from cadastral data only was proposed by Perez-Docampo et al. [9], but seismic risk data are essential in accurately estimating the loss produced by an earthquake and the response to an emergency situation.

According to the European Exposure Model, which was developed using publicly available sources of information, and assesses the earthquake risk across Europe (Figure 1) [10], the data for Romania indicate that there are a total of 5,507,000 buildings and a population of 19,357,000, but these data need to be constantly monitored and updated for an efficient evaluation of the possible outcome of an emergency situation. To have a permanently up-to-date view regarding the building situation, using cadastral data is very important, as any new building, as well as any demolition of an existing building, are noted in the Cadastral Land Registry.

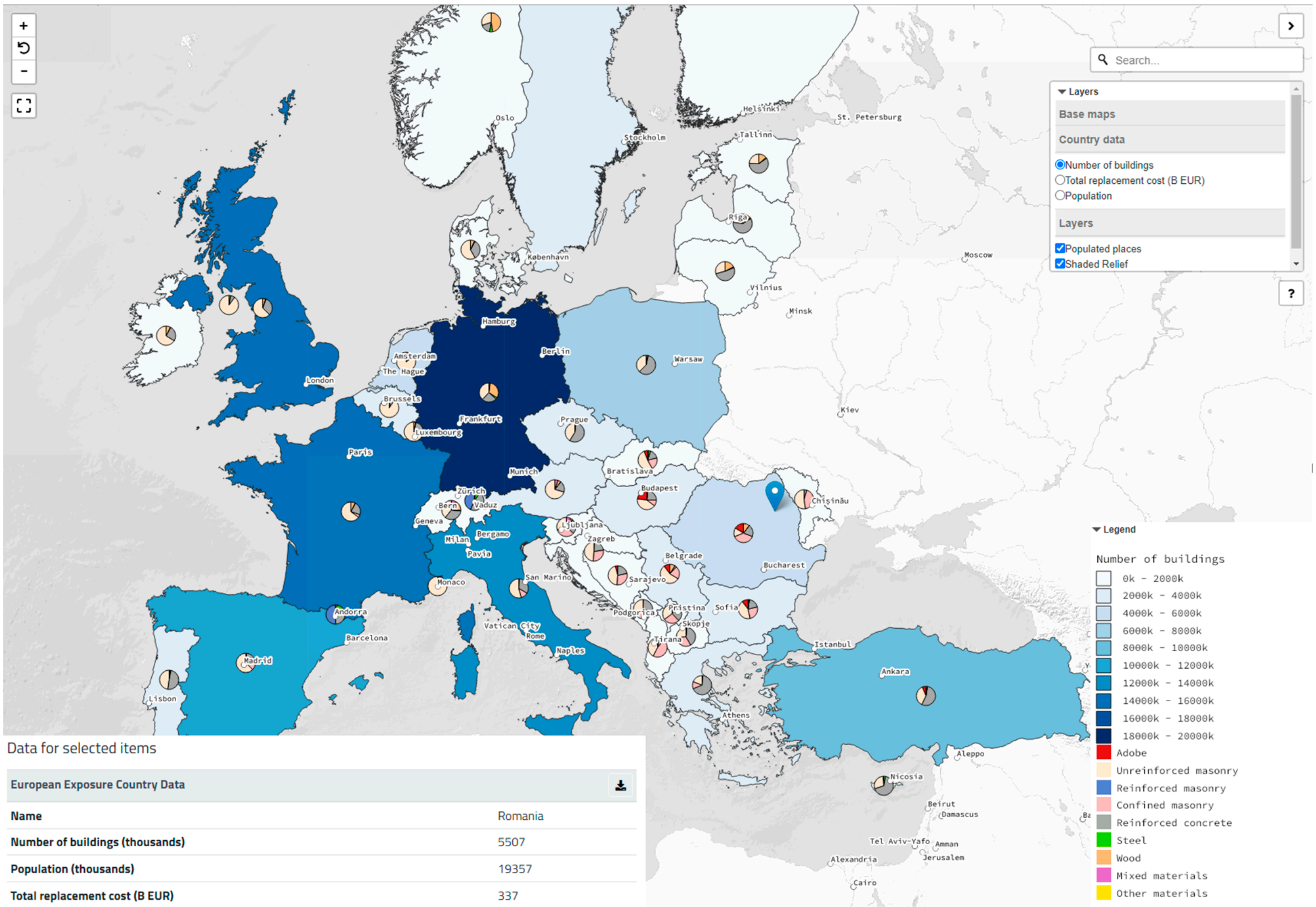


Figure 1. Earthquake risk across Europe [10].

2. Materials and Methods

2.1. Building Attributes in 3D City Models

Previous studies expressed the need for 3D data and seismic risk data integration, while mentioning but failing to collect and analyse essential data about the buildings, such as information about the reparation and consolidation of the buildings, as well as seismic risk and cadastral data integration. Moreover, previous attempts that resulted in seismic mapping [8] or a GIS framework for seismic loss assessment from cadastral data only [9] are not based on a thorough building attributes analysis. Therefore, in order to create a buildings database that can lay the groundwork for a 3D city model, we took into consideration other existing 3D city models and building databases and their attributes.

There are multiple examples of 3D models that represent either a part of the city or the entire city, and have multiple levels of details.

3D BAG is an open, up-to-date data set that contains 3D models of the buildings of the Netherlands at three different levels of details. The data used to generate this model are from the Register of Buildings and Addresses: Basisregistratie Adressen en Gebouwen—BAG [11], the National Height Model of the Netherlands: Actueel Hoogtebestand Nederland—AHN [12], the Large Scale Topographic Map of the Netherlands: Basisregistratie Grootschalige Topografie—BGT [13] and TOP10NL, part of the TOPNL data sets that belong to the Topographic Register of the Netherlands: Basisregistratie Topografie—BRT [14].

According to [15], out of all the geometrical objects from the BAG, the 3D BAG model uses only the buildings, which are represented as polygons that define the outline of the buildings as the projection seen from above, including the underground parts. These geometries are obtained from aerial images and terrestrial measurements, with a positional accuracy of 30 cm. The elevation data from the AHN are acquired by airborne laser scanning, with a density of 8 points per square meter, and are updated periodically. The BGT data consist of buildings and other objects, such as roads, waterways and railways, and are used to exclude the buildings that overlap these objects. The TOPNL data are open-source and were used to identify large warehouses and greenhouses, which raised issues due to their glass roofs.

In terms of semantic attributes, the BAG contains information about each address in a building, such as its current use, the date of construction and the registration status. The maintenance and the quality of these data used for the 3D BAG are ensured by the municipality.

To be able to manage the data set, the 3D BAG city model is divided into multiple tiles. For each tile, the data can be downloaded in three formats: CityJSON, OBJ and GPKG [16].

The attributes shown in the window that pops up when clicking on a building, which can be seen in Figure 2, are the tile number; the ID of the building (identificatie); the elevation above sea level at the ground level of the building (h_maaiveld); the elevation above sea level at the roof level, calculated as the 70th percentile of all elevation points on the corresponding roof part (h_dak_70p); the type of the roof (dak_type), which can have the following values: slanted, multiple horizontal, single horizontal, no points, cloud not detect, the source of the point cloud (pw_bron); the acquisition date of the point cloud (pw_datum); and the error codes for the 3D model (val3dity_codes). In addition, near the attributes button, there is the height from the ground to the selected point, as well as the slope of the surface [17].

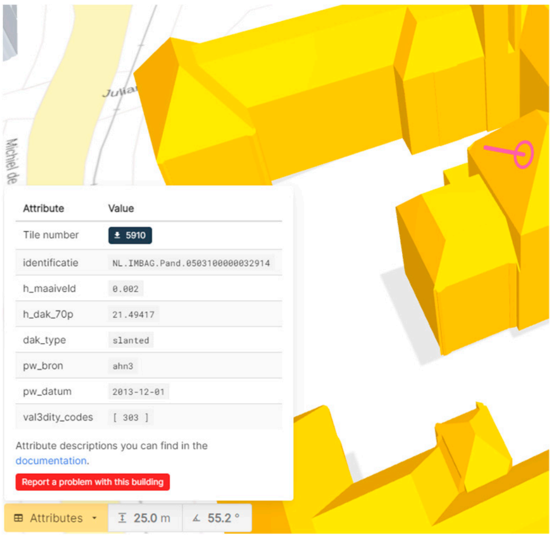


Figure 2. Pop-up attribute window in 3D BAG city model—LOD 2.2 [16].

Other relevant attributes included in the documentation are building registration history and version; building registration date; inclusion of the building in the BAG registration (yes/no); geometry ID; elevation above sea level at the level of the roof, calculated as the median of all elevation points on the corresponding roof part; elevation above sea level at roof level, calculated as the maximum of all elevation points on the corresponding roof part; elevation above sea level at roof level, calculated as the minimum of all elevation points on the corresponding roof part; whether the building is a greenhouse or a warehouse (yes/no); underground classification of the building or building part (floating/above ground/underground); building construction year; building part ID, as a building can have multiple parts; building surface semantics; and the current phase in the building's life cycle.

Helsinki has multiple versions of 3D models that include the reality mesh model (Figure 3), which shows Helsinki over several years (2017 and 2015) and Eliel Saarinen's city plan from 1915 and is based on aerial images; the city information model, which contains buildings and information on them such as property data, year of construction and number of floors, as well as the digital terrain model; and Helsinki's Energy and Climate Atlas, which is based on the city information model and includes information on energy, the consumption of water, heating and electricity and calculations of the solar energy potential of all surfaces [18].

Figure 3. Capture from the reality mesh model of Helsinki [19].

The city information model was made using a city map and spatial data, registers, laser scanning point clouds, aerial images and building information models. The buildings' footprints were transferred to a digital terrain model and were converted into 3D volumes using a surface model containing the shapes of the walls and roofs [20].

The city information model includes two different levels of detail—LOD1 and LOD2—and the visualization interface allows one to choose the level of detail as well as the base map, and whether to show the terrain model or not. The pop-up window shown when selecting a building (Figure 4) includes information about the building such as the building height above ground (Rakennuksen korkeus), the elevation above sea level at the ground level of the building (Rakennuksen pohjan korkeusasema) and three different identification numbers of the building (VTJ-PRT—persistent building identifier of the Population Information System in Finland; RATU—building identification number used in Helsinki and gmlid).

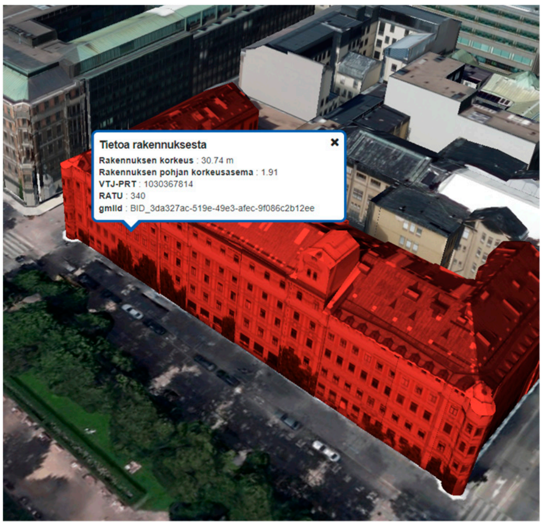


Figure 4. Pop-up window with building's attributes in the city information model of Helsinki [21].

Helsinki's Energy and Climate Atlas shows the energy potential, energy data containing basic information about the buildings from the Municipal Register (usage, building height from the ground, floor height, number of floors, building material), energy and repair information about the buildings and energy consumption data for buildings. It can also be switched to show a heating demand prediction [22] or the solar energy potential.

The window that pops up when selecting a building (Figure 5) shows information about the building such as address, building identification numbers, building usage, building height above ground, number of floors, floor height, usable area, built area, volume, building material, year of construction and energy-related information about the heating method, calculated energy consumption, water heating and building electricity.

Figure 5. Pop-up window with building's attributes from Helsinki's Energy and Climate Atlas [23].

The heating demand model shows the heating saving potential, the CO_2 emissions, the refurbishments' impact on heating demand and the heating demand in a changing climate. The window that pops up when selecting a building (Figure 6) shows information about the building such as identification numbers, address, the function of the building, the year of construction, number of stories above ground, the total floor area and the volume.

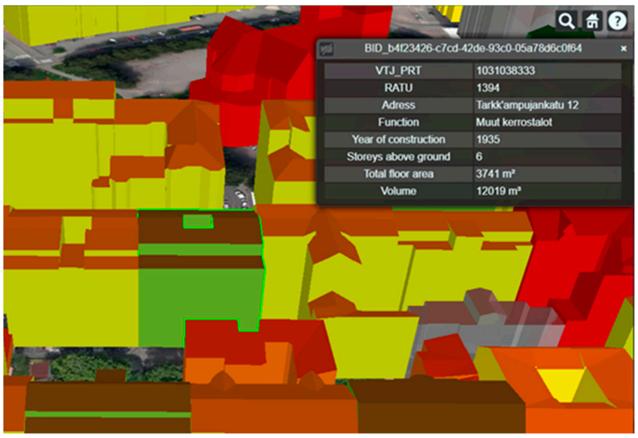


Figure 6. Pop-up window in Helsinki's Heating Demand Model [24].

The Boston 3D city model includes CAD, GIS and other third-party 3D models from developers and was created using the City of Boston's planimetric data from 2009–2010 and updated using models from the Boston Planning and Development Agency, third-party 3D models and digital twin producers. The model is divided into square tiles and the data can be downloaded separately for each tile in open-source data formats [25].

The ArcGIS Online web viewer offers the possibility to change the daylight and the shadow cast and to display various attributes when selecting the building (Figure 7), such as the name of the building (Name), a unique identifier (Model_ID), building ID (OBJECTID), the stage of the lifecycle of the building (Status), the source of the model (Survey_src), the date of the model (Model_dt), a hyperlink that shows an oblique view of the building in Google Streetmap (GoogleLnk), latitude and longitude of the centre of the building (Centr_Lat, Centr_Lon), the tile that contains the centre of the building (Tile_ID) and a hyperlink to the parcel viewed in the Boston Tax Parcel Viewer (Parcel_Lnk) [26].

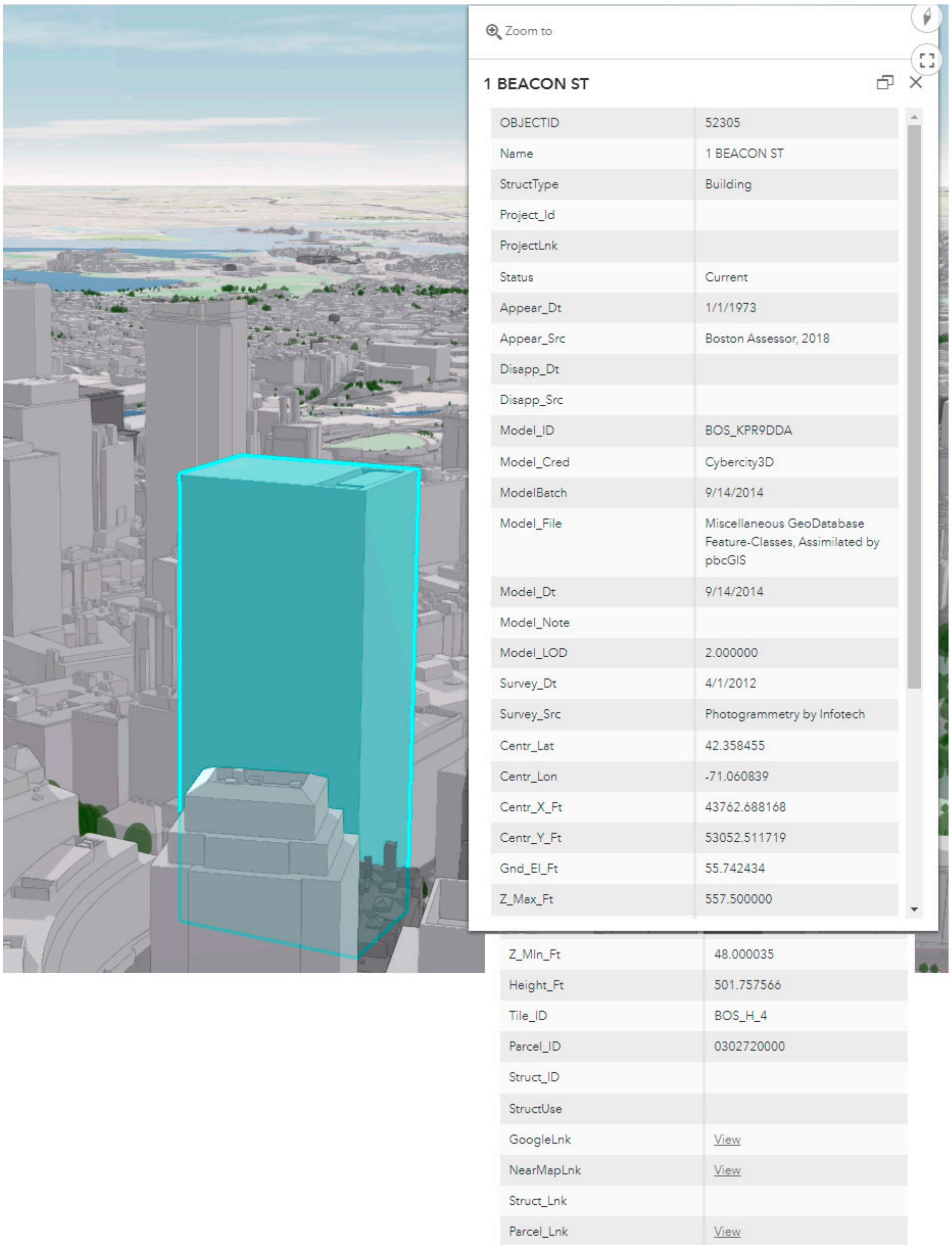


Figure 7. Attributes of the buildings in the Boston 3D city model ArcGIS online viewer [27].

The Boston Tax Parcel Viewer (Figure 8) is built by the City of Boston's central data organization—Citywide Analytics Team, and can be used to search for a parcel by address or PARCEL ID, zoom to the parcel and open a pop-up window to see the latest parcel data: parcel ID, address, owner, land use, lot size, living area, building value, land value, total value, gross tax [28].

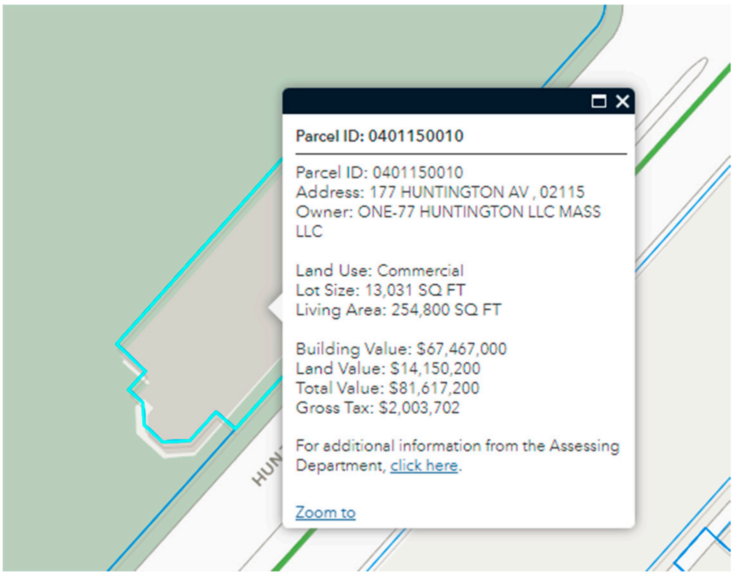


Figure 8. Boston Tax Parcel Viewer pop-up window showing parcel information [28].

A comparison between the building's attributes in the 3D BAG model, the Helsinki 3D city model and the Boston 3D city model is presented in Table 1.

The Zurich GIS browser is a web portal for the publication of geospatial data and is divided in three areas: content area, map window and information area. From the content area, a series of maps can be displayed, containing data such as the official cadastral survey; buildings data—regional employment offices, location classes, amelioration cadastre, sports facilities, residential buildings for nonprofit developers, civil protection organizations, fire brigade cooperation, fire departments jurisdictions; ground data—soil map of agricultural areas, crop rotation areas, map of anthropogenic soils, register of contaminated sites, agricultural suitability map, test perimeter for ground displacements, procedures in the event of indications of soil pollution; flora, fauna and vegetation data—aquatic neozoa, apiaries, fire blight low-prevalence areas, hunting grounds, habitat potential (wetlands, nutrient-poor, dry meadows), habitat mapping, corn rootworm spread, nature conservation documentation, neophyte distribution, light forests, maintenance plan for nature conservation areas, protective forests, forest property categories and forest districts, forest development plans, forest sites of natural history significance, wildfire corridors, vegetation-related mapping; leisure data—hiking trails, forests; geology data—geological-geomorphological inventory, geomorphological landscapes, modelled rock surface; georeferenced data—national maps, general plans, overview plan; history and culture data—historical water body map, historical maps, heritage maps, state archives, topographic names; limits—administrative divisions, fishing areas, community GIS; inventories and protected areas—amphibious migration sites, archaeological zones and historical monuments, federal inventories, geological-geomorphological inventory, inventory of sites of supramunicipal importance worthy of protection, inventory of historical transport routes, inventory of landscape protection objects, Infrastructure Conservation Management System; land use—slopes, agricultural zone boundaries, real estate and land cover, cantonal development areas for ecological compensation, climate suitability map, landscape quality, landscape typology, agricultural management; air and climate data—particulate matter emissions, heat in the settlement area, climate model, light emissions, CO_2 emissions, soot emissions, locations of transmitters; noise data—noise overview for construction projects, noise overview for room planning, traffic noise map, aircraft noise map; ortophotos, aerial and satellite images; location and address information; spatial planning and zoning plans—work zone management, employment statistics, building age, building statistics, ÖREB cadastre (cadastre of public property restrictions), neighborhood analysis, spatial population statistics, regional master plans, development status; topography data—digital elevation models and LiDAR flight data (Figure 9); environment data—priority potential areas for wetlands, risk register, chemical and biological risks; supply, disposal and communication data—energy plan, building volume, gravel resource, solar potential map, power grid areas, heat utilization atlas, wind potential; traffic data—construction sites on canton roads, pedestrian traffic potential, overall traffic model, heat stress in the street area map, public transport quality classes, travel times on roads, mobility routes, cable cars and ski lifts, signalized speed on cantonal roads, exceptional transport routes, traffic noise, road network, bicycle infrastructures, bicycle parking facilities, bicycle signaling, traffic measuring points and water data—drain process map, aquatic ecomorphology, water protection map, groundwater map, hydrological studies, hydrometric stations, natural hazard maps, public surface water, water space, water rights and flood retention basins, revitalization planning, maritime building cadastre [29].

Table 1. Comparison between the 3D BAG, the Helsinki 3D city model and the Boston 3D city model.

Attribute/Model	3D BAG—The Netherlands	Helsinki 3D Model	Boston 3D City Model
Building ID	x	x	x
Address	-	x	x
Building Part ID	x	-	
Coordinates	-	-	x
Current Use	x	x	-
Year of Construction	x	x	-
Registration Status	x	-	x
Registration Date	x	-	-
The Elevation above Sea Level at the Ground Level of the Building	x	x	x
The Elevation above Sea Level at the Roof Level	x	-	x
Roof Type	x	-	-
Source of the Geospatial Data	x	-	x
The Acquisition Date of the Geospatial Data	x	-	x
Slope of the Surface	x	-	-
Height above Ground	x	x	-
Property Information	-	x	-
Number of Floors	-	x	-
Floor Height	-	x	-
Energy/Water Consumption Information	-	x	-
Building Materials	-	x	-
Renovation/ Repair Status	-	x	-
Usable Area	-	x	-
Built Area	-	x	-

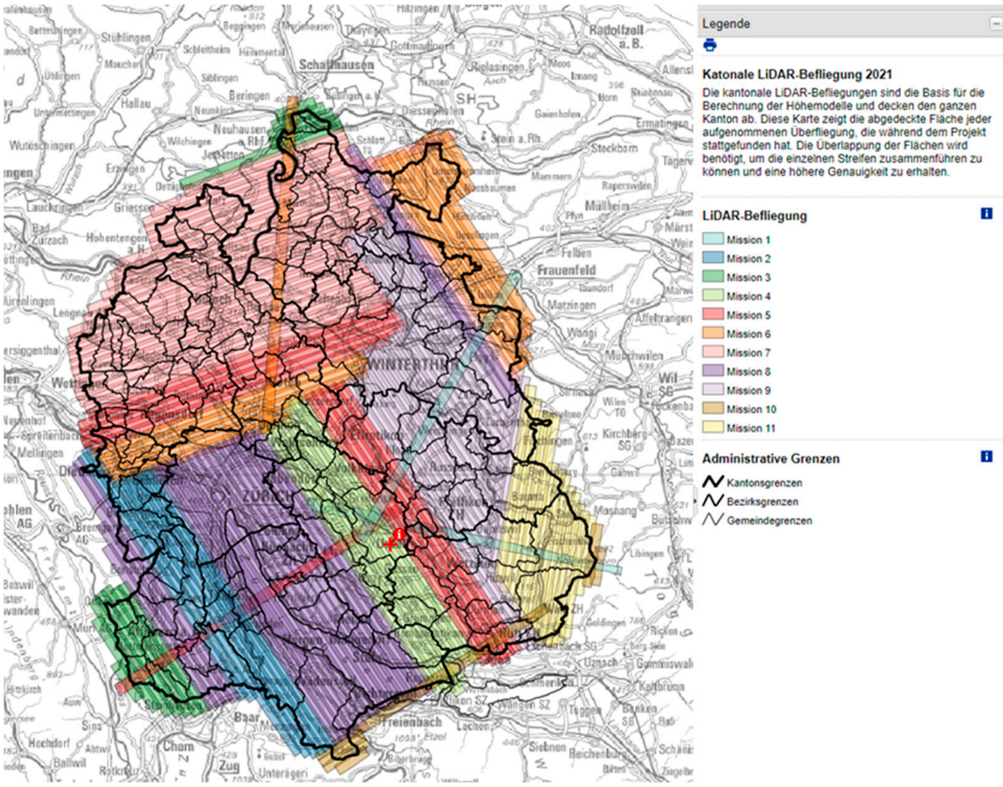


Figure 9. LiDAR point cloud coverage from the Zürich GIS browser [29].

Data such as the LiDAR point cloud, digital terrain model, ortophotos and vector data can be downloaded from the geoportal (Figure 10). The geoportal also allows for the utilization of tools to facilitate data understanding and extraction, such as pan button, selection, selection cancelling and measuring instruments for distances and surfaces.

Blatteinteilung DTM/DOM/LIDAR

Rasterzelle	2696_1241
DTM-Raster (50 cm)	Download (GeoTIFF)
DTM-Isohypsen (1 m)	Download (Shapefile)
DOM-Raster (50 cm)	Download (GeoTIFF)
nDOM Gebäude	Download (GeoTIFF)
nDOM Vegetation	Download (GeoTIFF)
LIDAR	Download (LAZ)
Markieren	

Blatteinteilung DOM/DTM/LIDAR

Gemeindegrenzen

Name	Bezirk	BFS-Nr.	Markieren
Mönchaltorf	Uster	196	

Gemeindegrenzen

Figure 10. Download menu from the Zürich GIS browser [29].

2.2. Building Attributes in Enriched 3D City Models

An enriched 3D city model should contain data that can be used in various fields. Structural attributes of the buildings describe the design, materials, scale, features or quality of a building or structure and can refer to the shape and size, materials, condition, age, etc. [30]. For hazard modelling, there are multiple building taxonomical classification schemes that include different building attribute groups. The GEM (Global Earthquake Model) scheme considers building attributes such as direction; material of the lateral-load resisting system; the lateral load-resisting system; height, including number of stories above ground; date of construction; occupancy (usage type); building position within a block; shape of the building plan; structural irregularity; exterior walls; the roof; the floor; and the foundation system. The Riskscape scheme considers in addition the floor height, condition, contents value, deprivation index, employee daily income, floor area, footprint area, occupancy (number of people), parapet, replacement cost, vehicles and vehicle value [31].

Leggieri et al. [32] assessed the need for information regarding potential seismic damage and losses and identified three different approaches for carrying out seismic assessment procedures, in which the level of detail is strictly connected to the size of the building stock. Therefore, for national, regional or urban scales, general data are required, such as building typology, structural material and age of construction; on an urban or district scale, morphological, geometric and structural features are necessary; and the third approach is applicable to single buildings and requires in-detail knowledge of them. In their study, they referred to building attributes such as structural typology (masonry, reinforced concrete and other material), class of age of construction, number of floors, maintenance state (bad, mediocre, good and excellent), typology of construction (civil building, dilapidated building, building under construction and underground building), area and height, based on which a seismic vulnerability index was calculated.

During the execution stage of the building, the building information model (BIM) can provide a common ground for the various parties involved in the construction process and can be integrated in GIS to develop a construction database, as shown in a study by Ebrahim et al. [33], where the attribute table contains the geometric shape and the lengths, areas and volume of each structural element. Moreover, the database was enriched with the executed quantities; the item specifications; all the reports issued at the project site, such as the safety report, engineer's instruction report, nonconformance report and materials inspection report; quality control; quality assurance; cost; planning; scheduling; sustainability; risk analysis; human resources; and equipment.

As GIS tools can provide the possibility to analyse issues specific to emergency and civil protection situations, providing the means for route calculations between facilities such as civil protection shelters and hospitals [34], BIM can be used for indoor navigation to facilitate disaster-related analysis and building evacuation, for which certain information is required: clear definitions of building stories, elements, spaces and usage; properties of each building element (wall materials, opening directions of the doors, doors used as exits); functional states of the building elements and movable objects; temporal changes in the building (if an area is temporarily inaccessible, for example); information on structural elements for the third dimension, including vertical elements such as columns, walls and stairs, in order to facilitate navigation to objects that are hidden such as pipes and cables; spatial relationships between elements (two floors connected with stairs, for example); and standardized definitions of the elements and spaces to ensure interoperability between different applications [35].

For urban energy planning, numerous attributes can be considered, such as construction period, primary envelope material, source of energy for space heating, and ventilation system type [36], which are used in the Norwegian strategy for advancing towards low energy use in buildings. Multiple studies have used 3D city models to simulate and model building energy consumption and potential. Katal et al. [37] used from official data sets the year of construction to estimate building envelope properties and the operation hours, average loads, appliances, lighting and the average usage rate to estimate the internal load, in order to obtain a building energy and microclimate model. According to Nouvel et al. [38], local weather data, such as temperatures and radiations, can be used in addition to the building geometrical data (volume, height, boundary surface type and orientation, number of stories, calculated based on the building height and story height if missing), building physical attributes based on the year of construction and the building function and building usage attributes and operating parameters such as occupancy time, air change requirement and set-point temperatures. Redweik and Catita [39] emphasized the influence of the slope and the aspect (azimuth) of a surface in the process of generating a solar radiation model based on LiDAR data.

2.3. Building Databases

The EU Building Database contains information about building stock characteristics (building type, stock by age, density, households by size, floor area, residential/nonresidential, building permits, etc.), building shell performance (air tightness, U-value of building envelope, external walls, floors, doors, roofs, skylight or windows), technical building systems (space heating, water heating, appliances, cooking, lighting, space cooling, on-site energy generation, embodied energy), nearly zero-energy buildings, building renovation, energy consumption (energy use per building, energy use per square meter, etc.), certification, financing, energy poverty (risk of poverty, housing deprivation, economic strain, living conditions, social issues) and energy market (average energy prices, liberalization, switching rates, change of supplier, disconnection rates), and can be queried by selecting the indicators, countries and years. The data can be downloaded in Excel format and used for reporting purposes [40].

Another example of a building database is the New York City Building Information System, which can be queried by property (address, building identification number, block or lot), complaint, summons or violation (number or date), job application (job number, permit number, permits by issue date, permits by applicant, work order by license, jobs by community board, etc.), gas service authorization (by date), power authorization (by date), elevator device (by number) and cranes and derricks (by number). The Building Information System contains a profile page for properties in New York City that lists related jobs and occupancy information in addition to other actions including complaints, violations and inspections [41].

Pavic et al. [42] used multiple types of information in the creation of the Osijek building database, such as building location information (address, cadastral number), the position of the building in relation to the particular city block, general information (the purpose of the building, the year of construction and/or reconstruction, the number of persons living in the household), information on the geometric characteristics of the building (floor plan dimensions, net and gross floor planes, floor plan blueprints, floor level, floor space and total height), regularity in floor plan and height, information on the main structural system of the building, information on building materials used, information on the roof structure and cover.

Canada's Open Database of Buildings (ODB) is a collection of open data of buildings, consisting mainly of building footprints. The attributes included in the database are latitude, longitude, area, perimeter, data provider, census subdivision unique identifier, census subdivision name and unique building ID, and are provided by municipal, regional or provincial sources available to the general public through open government portals [43].

TABULA WebTool [44] is a webtool that provides information about buildings in Germany, Denmark, England, Greece, Netherlands, Norway, Slovenia, Austria, Spain, Italy, Belgium, Cyprus, Czech Republic, France, Hungary and Ireland, but the information provided focuses on energy demand.

2.4. Proposal for a Building Database for Romania

2.4.1. Building Attributes

Based on analysing the buildings attributes included in the above mentioned 3D city models and building databases, we proposed a list of attributes in Table 2, suitable for a building database for Romania.

Table 2. List of attributes proposed for a building database in Romania, with data availability and possible sources.

Attribute/Data	Availability	Existing/Proposed Source
Building ID	-	-
Building cadastral number	Partial	e-Terra3
Land cadastral number	Partial	e-Terra3
Address	No	e-Terra3
Coordinates	No	Automatically extracted from ArcGIS
Building destination	Partial	e-Terra3
Land usage	Partial	e-Terra3
Property information	Partial	e-Terra3
Construction status	No	Building-by-building surveys
Year of construction	Partial	e-Terra3
Building authorization number	Partial	
Building authorization date	Partial	E-Terra3 /City Hall Inventory
Building certificate number	Partial	E-Terra3 /City Hall Inventory
Building certificate date	Partial	E-Terra3 /City Hall Inventory
The elevation above sea level at the ground level of the building	No	LiDAR
The elevation above sea level at the roof level	No	LiDAR
Building height	No	LiDAR
Number of floors	Partial	e-Terra3, LiDAR
Floor height	No	LiDAR
Footprint area	Partial	e-Terra3, LiDAR
Usable area	Partial	LiDAR
Built area	Partial	e-Terra3, LiDAR
Source of the geospatial data	-	-
The acquisition date of the geospatial data	-	-
Slope of the surface	No	LiDAR
Building orientation	No	Building-by-building surveys, Google Street View
Foundation system by depth	No	BIM
Foundation system by material	No	BIM
Foundation system by shape	No	BIM
Building exterior walls	Currently being disseminated	Census

Table 2. *Cont.*

Attribute/Data	Availability	Existing/Proposed Source
Structural typology	No	BIM
Roof type by material	No	BIM, photogrammetry
Roof type by slope	No	BIM, photogrammetry, LiDAR
Roof type by shape	No	BIM, photogrammetry
Seismic risk assessed	Only in Bucharest	Municipal Administration for the Consolidation of Buildings with Seismic Risk
Subprogram I—multistory buildings with the main destination being residential	No	-
Subprogram II—buildings of interest and public utility	No	-
Has a height regime of minimum ground floor+3 floors if included in sub-program I	No	-
Has a minimum of 10 apartments, if included in subprogram I	No	-
Importance class of the building, if included in subprogram II	No	-
The peak value of the ground acceleration for earthquake design a (g), according to the zoning map of the Romanian territory from Seismic Design Code P100-1, is greater than or equal to 0.20 g, if included in subprogram I or II	No	-
Condition	No	Building-by-building surveys
Renovation status	No	Building-by-building surveys
Thermal rehabilitation status	Currently being disseminated	Census
Joinery type	Currently being disseminated	Census
Type of space heating	No	Census
Source of energy for space heating	Currently being disseminated	Census
Source for water	Currently being disseminated	Census
Type of fuel used for cooking	Currently being disseminated	Census
On-site energy generation	Currently being disseminated	Census
Occupancy (number of people)	Currently being disseminated	Census
Data maintenance state	-	

In the following section, we will explain the meaning of the chosen attributes and their possible values.

The land cadastral number and building cadastral number are unique numbers and are attributed through a first registration documentation [45]. The data are available via the e-Terra3 application (Figure 11) for ANCPI (National Agency for Cadastre and Real Estate) authorized personnel, or open-source via the ANCPI geoportal (Figure 12).

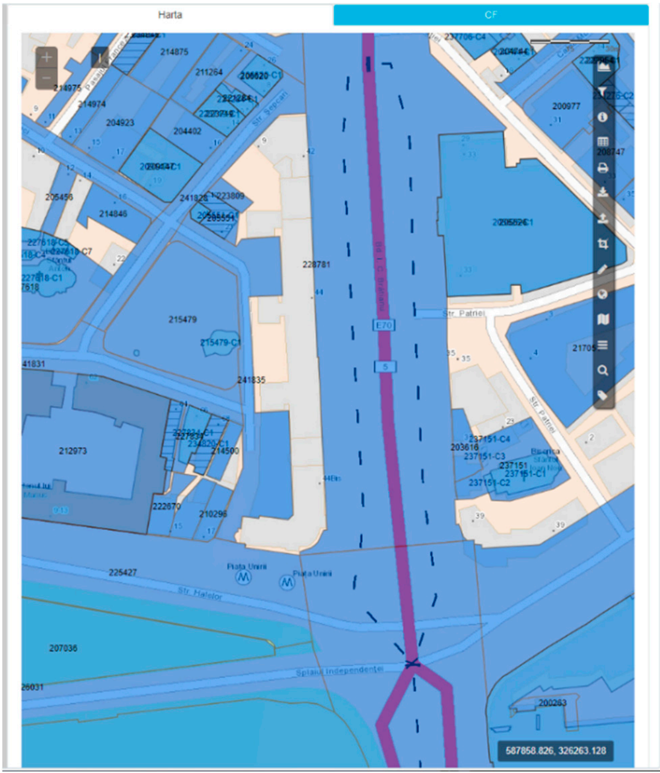


Figure 11. Capture from E-Terra3 application [46].

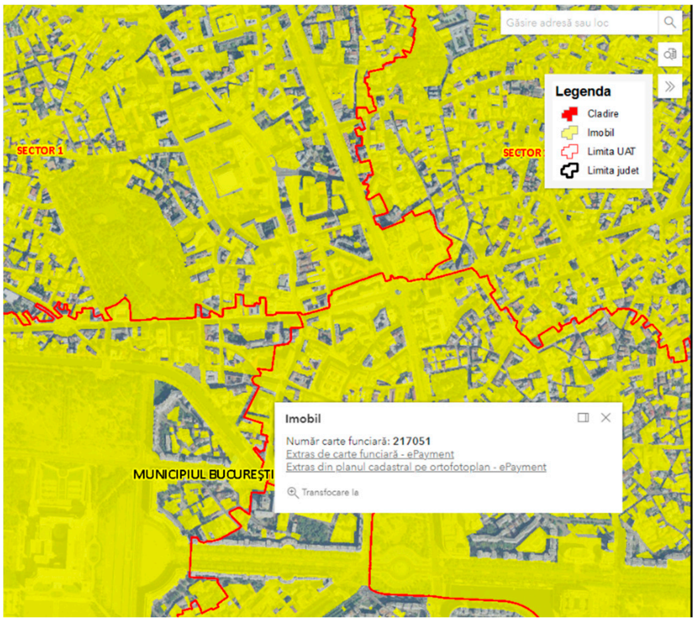


Figure 12. Capture from the ANCPI geoportal [47].

The main land parcel usage categories in Romania, specified by the order 600/2023 [48], are arable; grassland; meadows; vineyards; orchards; forests and other lands with forest vegetation; land with running water; land with standing water; road communications; railways; land occupied by buildings and yards; and unproductive and degraded land.

The order 600/2023 also specifies the main building destination categories as follows: housing, administrative and sociocultural buildings; industrial and urban buildings; and annex buildings.

The building authorization is the act of authority of the local public administration—county, municipal, city or communal, based on which construction works can be executed [49].

The building attestation certificate is an administrative document issued by the city hall, and it certifies that the building had a construction permit or other appropriate documents.

According to Law no. 212 [50], multistory buildings with the main destination being residential are those existing buildings that consist of spaces with the main destination being residential and in which there may be public spaces with other destinations than residential, distributed on multiple levels, including the attic. Buildings of interest and public utility are those existing buildings that include spaces where activities in the fields of general, community or social public interest are carried out and where the presence of the temporary or permanent public in the total exposed area is involved. The National Program for Consolidation of the Buildings with a High Seismic Risk consists of two subprograms:

I. The subprogram for the design and execution of intervention works for multistory buildings with the main residential destination;
II. The subprogram for the design and execution of intervention works for buildings of public interest and utility owned or managed by the central or local public administration authorities and institutions.

Buildings from subprogram I can be included only if they meet the following criteria:

- Having a height regime of minimum ground floor+3 floors and minimum 10 apartments;
- The peak value of the ground acceleration for earthquake design a (g), according to the zoning map of the Romanian territory from the Seismic Design Code P100-1, being greater than or equal to 0.20 g.

Buildings from subprogram II can be included only if they meet the following criteria:

- The importance class of the building being either I or II.
- The peak value of the ground acceleration for earthquake design a (g), according to the zoning map of the Romanian territory from the Seismic Design Code P100-1, being greater than or equal to 0.20 g.

According to [51], foundations can be classified by depth in surface foundations and depth foundations; by material in rigid foundations: natural stone, simple concrete and elastic foundations: reinforced concrete and by shape in isolated foundations, continuous foundations, under walls or pillars and foundations with beam networks. Structures can be classified by material in wooden structures, monolithic reinforced concrete structures, prefabricated reinforced concrete structures, masonry structures, metallic structures and mixed structures. Roofs can be classified by material in wooden roofs, reinforced concrete roofs and metallic roofs; by slope in terrace roofs (with a slope of less than 7%) and roof frames (with a slope greater than 7%); and by shape in roofs curved in one direction, roofs curved in two directions and saddle roofs (hyperbolic paraboloid).

2.4.2. Data Sources

For the data regarding the population and the households, we propose to use the census data. The Population Census of Romania started in February 2022 and was finalized by the end of the year. The data collected include information about the people and the household, including information about the sources of energy, water, cooking fuel, on-site energy generation, joinery type, thermal rehabilitation status and number of people per household. The results of the census are meant to be disseminated by December 2023 [52].

The cadastral data can be provided by E-Terra3, the national property registration system of Romania, which allows for cadastral documentation management, registries management, data conversion, technical documentation reception, report generation, land book registration, map visualization of properties, electronic document signing and electronic archiving of documents [53]. The archived data are available for ANCPI authorized personnel, and include information about the land parcels and buildings such as land cadastral number, building cadastral number, address, building destination, parcel usage, property information, year of construction, building authorization number, building authorization date, building certificate number, building certificate date, number of floors, building footprint area, building usable area and built area. The geometries of the land parcels and buildings' footprints can be exported in a .dxf or .shp format and can be used as a base for the 3D model, by extruding the footprint at the height of the building to obtain a volume. The disadvantage of using e-Terra3 data is the lack of consistency in the data, as they only cover 54,26% of the country [54], and even so, the mentioned data are not available for all the registered properties.

Seismic risk data are provided by the Municipal Administration for the Consolidation of Buildings with Seismic Risk, a public service that aims to reduce the seismic risk of existing buildings in Bucharest, in the context of mitigating the effects of a potential earthquake, which acts to implement measures to intervene in the cases of buildings with insufficient levels of earthquake protection [55]. In this regard, they released a list of buildings technically expertized from the seismic risk point of view, which includes class I, II, III and IV of seismic risk properties; a list of consolidated properties; a list of properties that are considered emergencies, but have not been attributed a certain seismic risk category; and a list of other properties that have not been attributed a certain seismic risk category. The list contains information about the address, the number of apartments in the building, the number of floors, the year of construction, the building area and the name of the certified technical expert involved in the expertise.

Class I of seismic risk consists of the buildings with susceptibility to totally or partially collapse under the action of the limit projected earthquake movement; class II of seismic risk includes the buildings susceptible to major damage, which endangers the residents' lives but whose totally or partially collapse has a low probability; class III of seismic risk includes the buildings susceptible to moderate damage, which may endanger the residents' lives; and class IV of seismic risk consists of buildings whose response to the action of the limit projected earthquake movement is similar to the one expected for the buildings designed according to the technical regulations in force [50].

The Pre-Quake project is meant to identify the factors that made and could have made a bigger difference in terms of hazard research, risk and vulnerability during and after major earthquakes; to analyse the capabilities of new technologies to provide useful information before, during and after an earthquake; and to create sets of instructions and to implement methodologies and software applications for the analysis of the mode and locations in which the ground motion parameters generated by earthquakes and the effects of earthquakes are recorded in Romania [56]. A web GIS application was created in order to facilitate the analysis of the geospatial data and to better understand the seismic vulnerability of the city of Bucharest. The previously mentioned data from The Municipal Administration for the Consolidation of Buildings with Seismic Risk were digitalized, imported in ArcGIS Online and used for the application.

A LiDAR point cloud can be acquisitioned and used to model the volumes that define the buildings, obtaining data such as the elevation above sea level at the ground level of the building, the elevation above sea level at the roof level, building height, floor height (can also be obtained by dividing the building height by the number of floors) and the slope of the surfaces. Satellite imagery can also be used in the process of modelling, by extracting the buildings' footprints using machine learning algorithms to compensate the lack of data from the e-Terra3 system.

Recent studies [57] have shown that machine learning algorithms can be used to predict and assess the structural performance of the building, by extracting patterns from data collected from various sources and identifying the building's structural condition.

The building information model (BIM), where available, can cover for important data such as building geometries, spatial relationships, geographic information, quantities and properties of building components and materials, and it can describe the entire life cycle of the building [33].

Eventually, building-by-building surveys can offer the possibility to cover for some of the missing data, but are not a viable option for large-scale areas due to the long time needed to acquire the data.

3. Study Area and Data

The area of study is located in the Historic Centre of Bucharest City (Figure 13). This area is notorious for its old buildings, which were severely damaged by the 7.4 magnitude earthquake in 1977, and which are exposed to more seismic activity from the Vrancea region, a complex seismic zone of continental convergence, located at the contact of three tectonic plates: the East-European plate, the Intra-Alpine plate and the Moessian plate [58]. In this regard, a survey was conducted on the population of Bucharest with the purpose of population awareness and preparedness evaluation in the event of an earthquake produced in the Vrancea region. The results showed that a very limited number of people are prepared to deal with such an event [59]. As the study area poses such a high risk in case of an earthquake and the population proved to be unprepared for such an event, seismic risk data are crucial in earthquake damage estimation and emergency response planning.

Figure 13. Capture from Google Earth of the study area highlighted with yellow.

The first step was collecting field data through the ArcGIS Survey 123 application (Figure 14). A form containing the fields mentioned above was created in order to ease the process. Collected data included building ID, building address, construction status, number of floors above ground and observations, building condition, foundation system, building exterior walls, renovation status, thermal rehabilitation status and joinery type, based on visual assessment on site. Pictures of the buildings (Figure 15) were taken as well.

The field-collected data were correlated and updated with E-terra 3 data (Figures 16 and 17) to obtain additional information about the buildings such as building cadastral number, land cadastral number, building destination, land usage, number of floors, building footprint area and building footprint geometry.

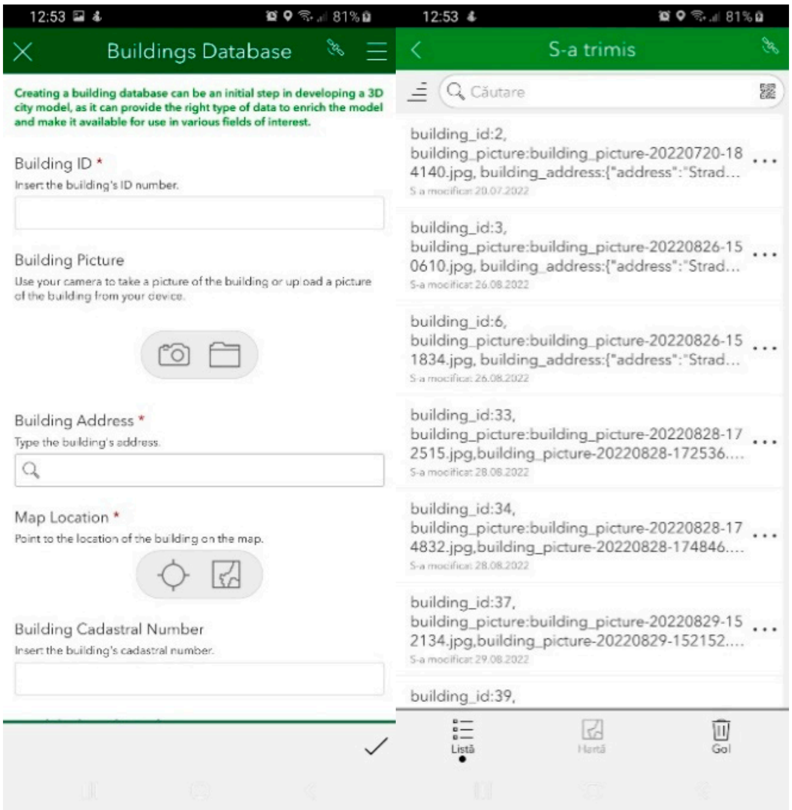


Figure 14. Captures from the ArcGIS Survey 123 application; attributes marked with * are mandatory.

Figure 15. Building pictures.

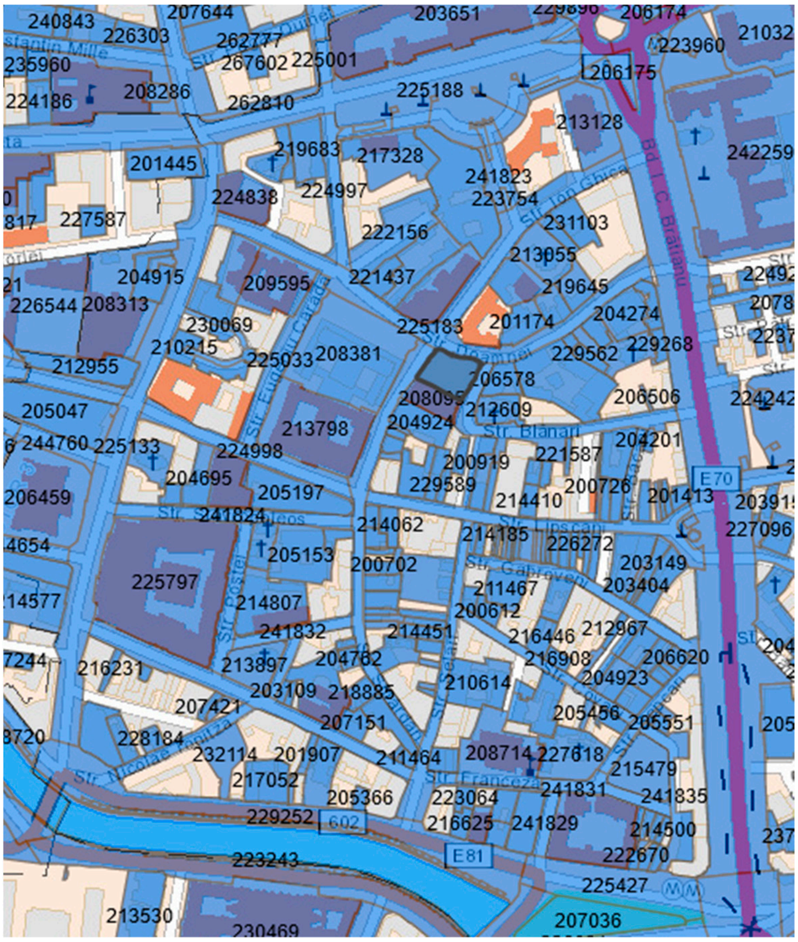


Figure 16. Capture from the E-Terra 3 application.

Tip	IE	CAD	TOP	CF	NR CAD GEN	S. Masurata	S. din acte	Adresa	Actiuni
T	**213128**	**12203**		**99852**		**2456**	**2456**	**Bucuresti Sectorul 3,Bulevardul BRATIANU C. ION,nr. 2**	
C	213128-C1	C1		99852	0			Bucuresti Sectorul 3,Bulevardul BRATIANU C. ION,nr. 2	

10 25 50 100

Figure 17. Capture from the E-Terra 3 application.

Additional information was correlated from the list published by The Municipal Administration for the Consolidation of Buildings with Seismic Risk [55], such as the construction, the year of the technical expertise and the seismic risk assessed.

The National Program for the Consolidation of Seismic Risk Buildings (PNCCRS) is run by the Ministry of Development, and was allocated a budget for the full financing of the consolidation of some buildings in historically protected areas [55]. Among the buildings that are part of the current study, five were proposed for consolidation.

From a surveyor's perspective, the building's footprint area and precise coordinates are very important, as they provide the exact location and surface of the building, determined by ANCPI authorized personnel. Therefore, we added the building's footprints exported from E-Terra 3 to the map. The result is displayed on the map in Figure 18, classified by seismic risk, and in the attribute table in Figure 19.

Figure 18. ArcGIS online map viewing of the collected data.

Building ID	Building ID number	Building Address	Building Cadastral Number	Land Cadastral Number	Building Destination	Land Usage	Construction Status	Year of Construction	Building Authoris Number
1	1.00	Strada Franceza 66, Sectorul 3, Bucuresti, ROU	227834-C1	227834	Housing	Land Occupied by Buildings and Yards	Finished	1870	
2	2.00	Strada Franceza 64, Sectorul 3, Bucuresti, ROU	229869-C1	229869	Housing	Land Occupied by Buildings and Yards	Finished	1870	
3	3.00	Strada Franceza 58, 030106, Sectorul 3, Bucuresti, ROU	221017-C1	221017	Housing	Land Occupied by Buildings and Yards	Finished	1890	
4	4.00	Strada Franceza 56, 030106, Sectorul 3, Bucuresti, ROU					Finished	1870	

Figure 19. Capture of the attribute table of the collected data.

4. Results and Analysis

Based on analysing the current state of the art regarding the building attributes mentioned in various 3D city models and building databases, we were able to propose a structure for a building database in Romania that can lay the groundwork for further 3D city modelling, while playing an important role in seismic risk assessment and emergency response management. The result of our study was an online GIS application that is used to collect, display and analyse the necessary data to create a building database. In addition to previously mentioned research in the field, such as the application that integrates cadastral data only for seismic risk assessment [9], or the study by Lates and Crenganis [8] that resulted in a seismic risk map, this study integrates cadastral data with seismic risk data while also mentioning the importance of other data, such as energy demand, household, population and other information about the buildings, in an online database that can make seismic risk management more efficient and can lay the groundwork for further 3D city model development, which will further improve the process.

By analysing the data, we noticed that 64.71% of the buildings for which the destination was known (14.77% of the total of buildings) are classified as Housing, 32.35% (7.38% of the total of buildings) are Administrative and Socio-Cultural and 2.94% (0.67% of the total of buildings) are Industrial and Urban (Figure 20). We also analysed the data by the number of floors above ground (Figure 21), noticing that most buildings are 3–4 floors, by the seismic risk assessed, most of them being in the emergency category, followed by seismic risk I and seismic risk II (Figure 22); and by their condition (Figure 23), concluding that 2.01% of the buildings are in a very bad condition, 30.87% are in a bad condition, 46.98% are in a neutral condition, 16.78% are in a good condition and 0% are in a very good condition.

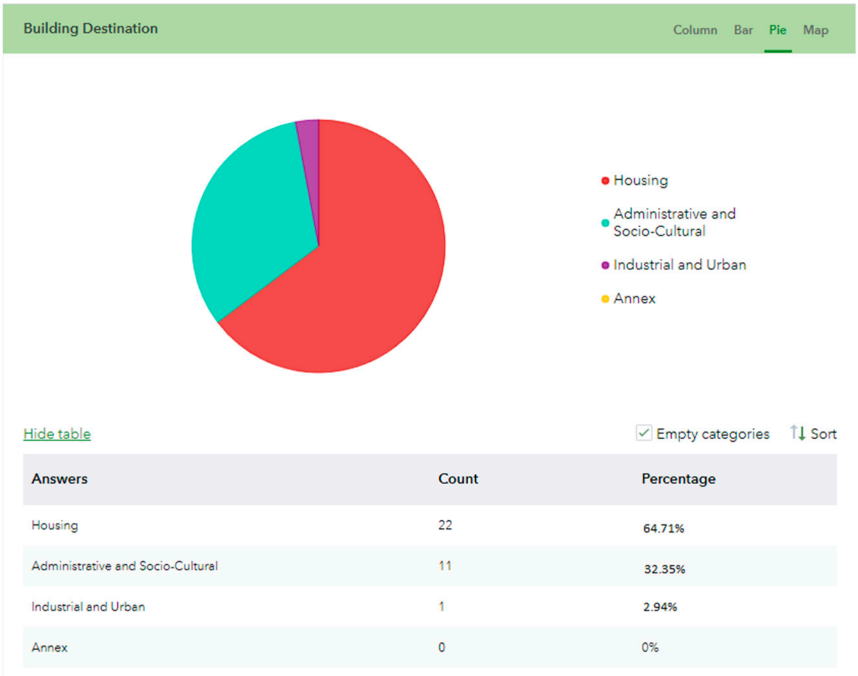


Figure 20. Building destination chart.

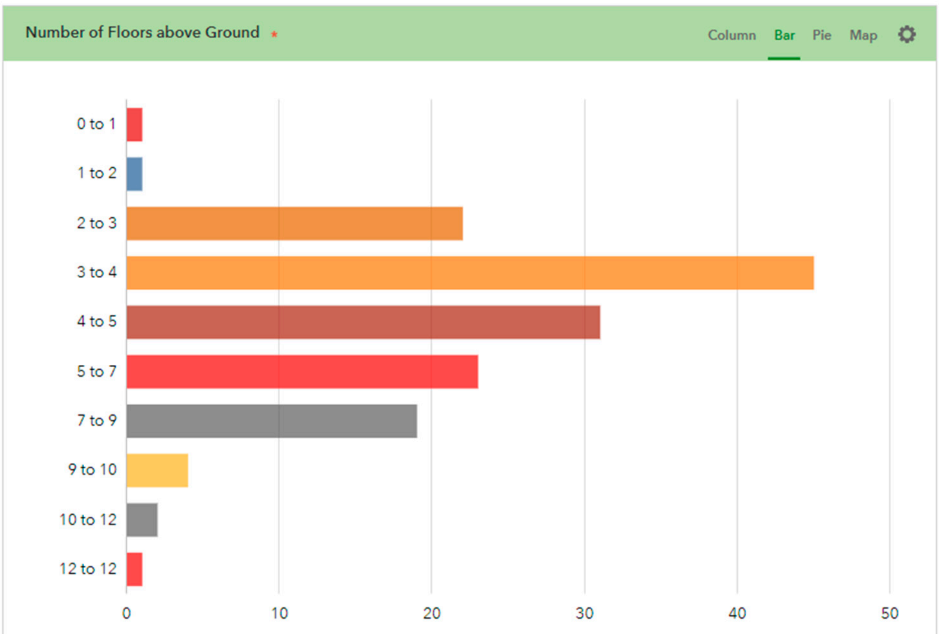
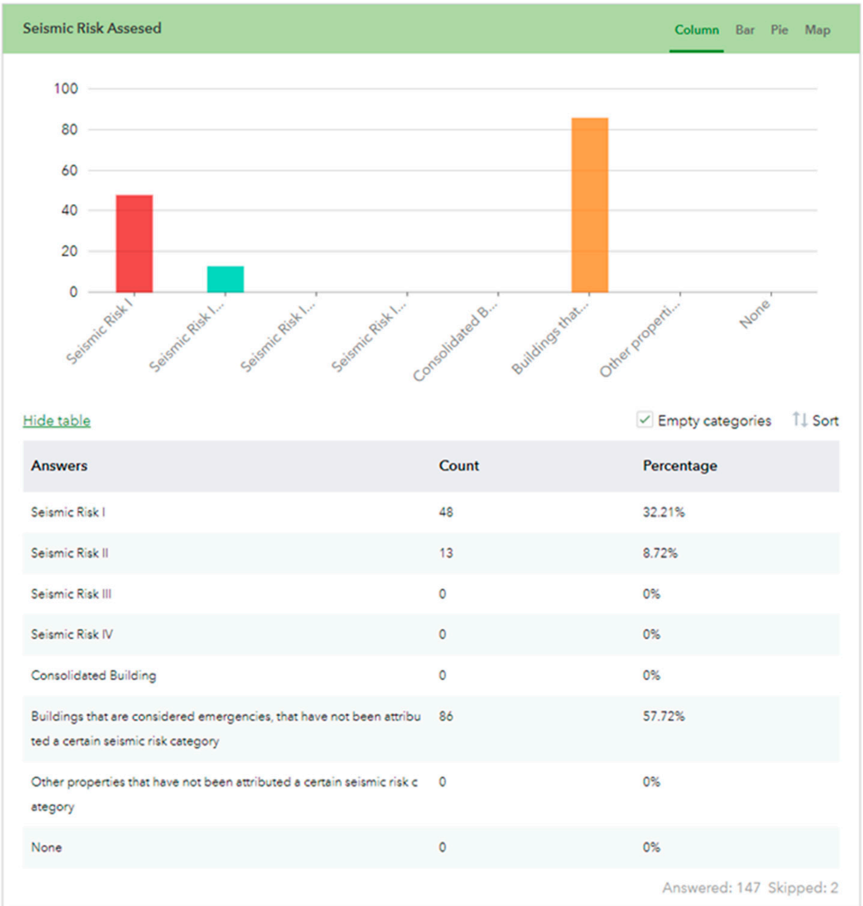
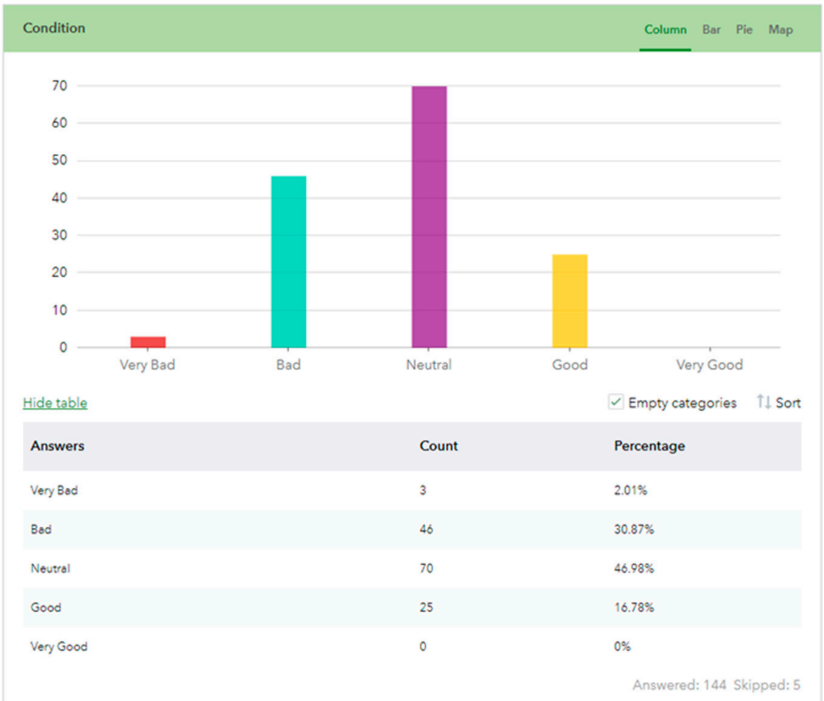


Figure 21. Number of floors above ground graphic.



Answers	Count	Percentage
Seismic Risk I	48	32.21%
Seismic Risk II	13	8.72%
Seismic Risk III	0	0%
Seismic Risk IV	0	0%
Consolidated Building	0	0%
Buildings that are considered emergencies, that have not been attributed a certain seismic risk category	86	57.72%
Other properties that have not been attributed a certain seismic risk category	0	0%
None	0	0%

Figure 22. Buildings' seismic risk graphic.



Answers	Count	Percentage
Very Bad	3	2.01%
Bad	46	30.87%
Neutral	70	46.98%
Good	25	16.78%
Very Good	0	0%

Figure 23. Buildings' condition graphic.

5. Discussion

Three-dimensional data were available as a web layer in ArcGIS Online (Figure 24), but the source and the acquisition technique of the data is unknown, and it proved to be in disagreement with the cadastral data, as the 3D buildings were not matching with the footprints exported from e-Terra 3. Therefore, a LiDAR point cloud is required in order to accurately represent the 3D building geometries.

Figure 24. 3D building web layer in ArcGIS Online and 2D view with registered buildings in an online web app.

Creating an ArcGIS Dashboard (Figure 25) offers a comprehensive view of the data, transparency and an easier access for the citizens and stakeholders. As the municipality provides the required data, a dashboard can play a role in event monitoring and decision making. The dashboard shows a minimum built area of 50 square meters, an average value floor number of 4.3 and a total of 147 buildings with seismic risk, out of which 32 are registered in the eTerra System and 5 are included in PNCCRS.

To emphasize the utility of the dashboard, which shows the statistics for the area within the visible section of the map, we selected the area exposed to the main neighboring boulevard, and in Figure 26, we can see that the minimum built area is 53 square meters and there are 14 buildings with seismic risk exposed to the boulevard, with an average value of floor number of 4.9, out of which 50% are considered emergencies, 42.86% are assessed seismic risk I and 7.14% are assessed seismic risk II.

ArcGIS Insights provided the possibility to combine data analysis with data visualization, allowing us to perform and display different analyses. One analysis we performed was the correlation between the year of construction and the year of the technical expertise (Figure 27), and we determined that a total of nine buildings that were built in 1900 received technical expertise in 1993. This type of analysis is necessary for a better evaluation of the situation regarding the number of buildings that have received or need to receive technical expertise.

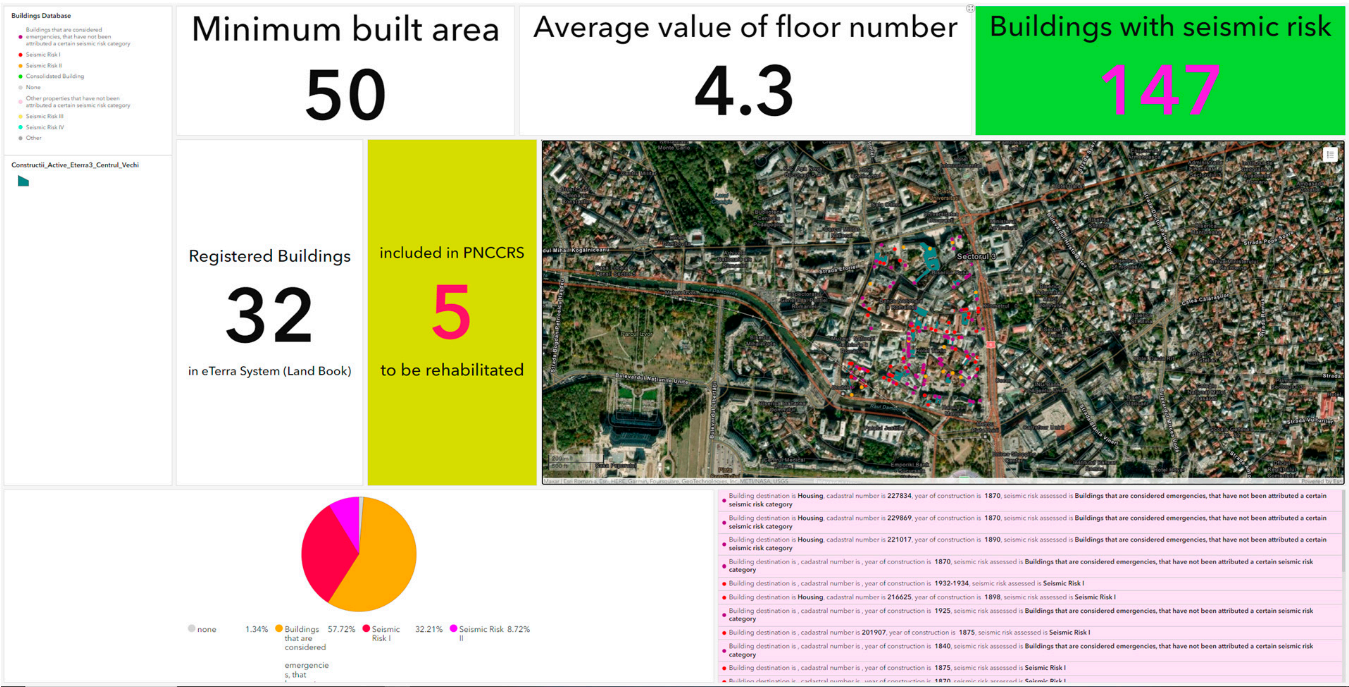


Figure 25. Building database for the Historical Centre of Bucharest ArcGIS dashboard.

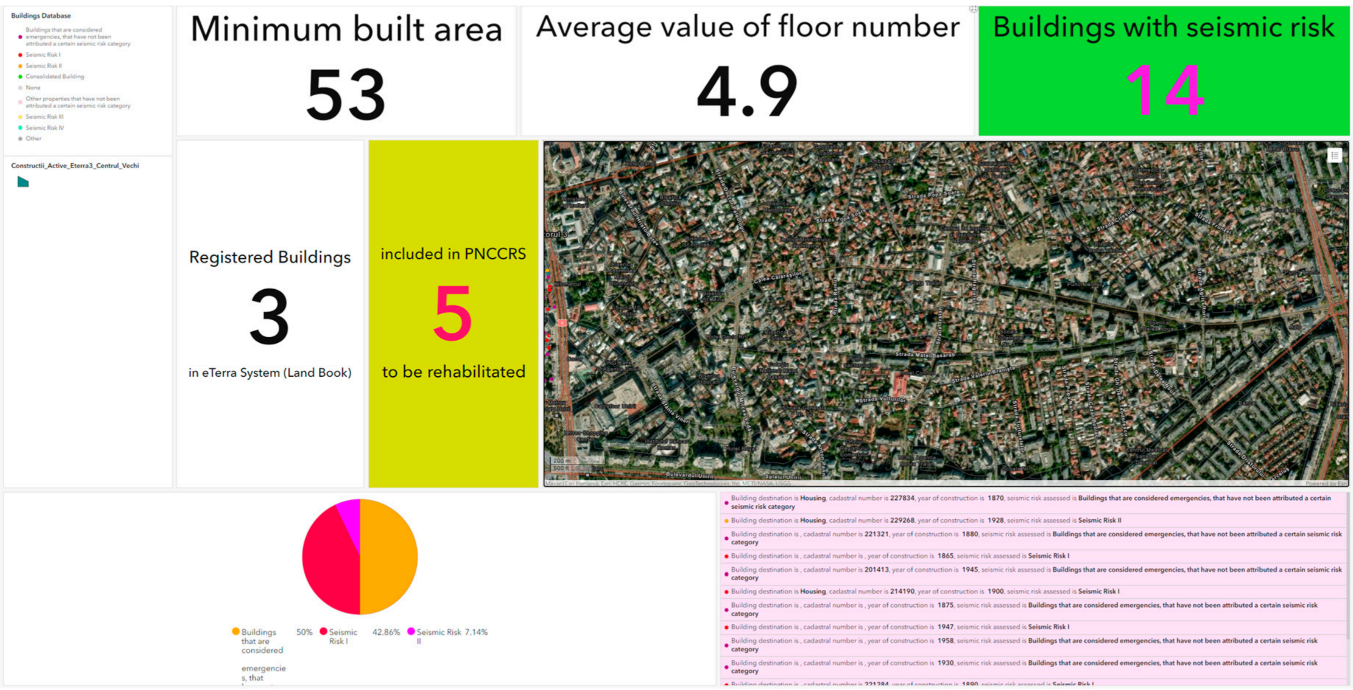


Figure 26. Building database for the Historical Centre of Bucharest ArcGIS dashboard.

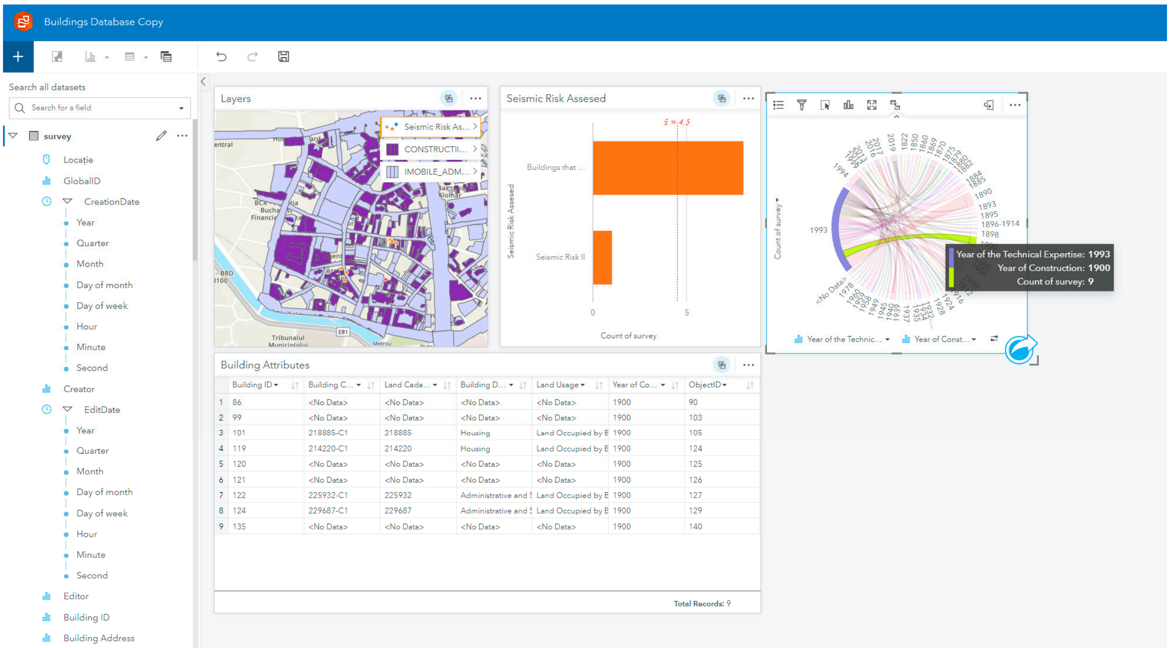


Figure 27. The correlation between the year of construction and the year of the technical expertise.

Another analysis we performed was to assess the number of buildings that are not renovated and are not included in the National Program for the Consolidation of Buildings with Seismic Risk (Figure 28), and we determined that a total of 110 buildings are neither renovated nor included in the PNCCRS.

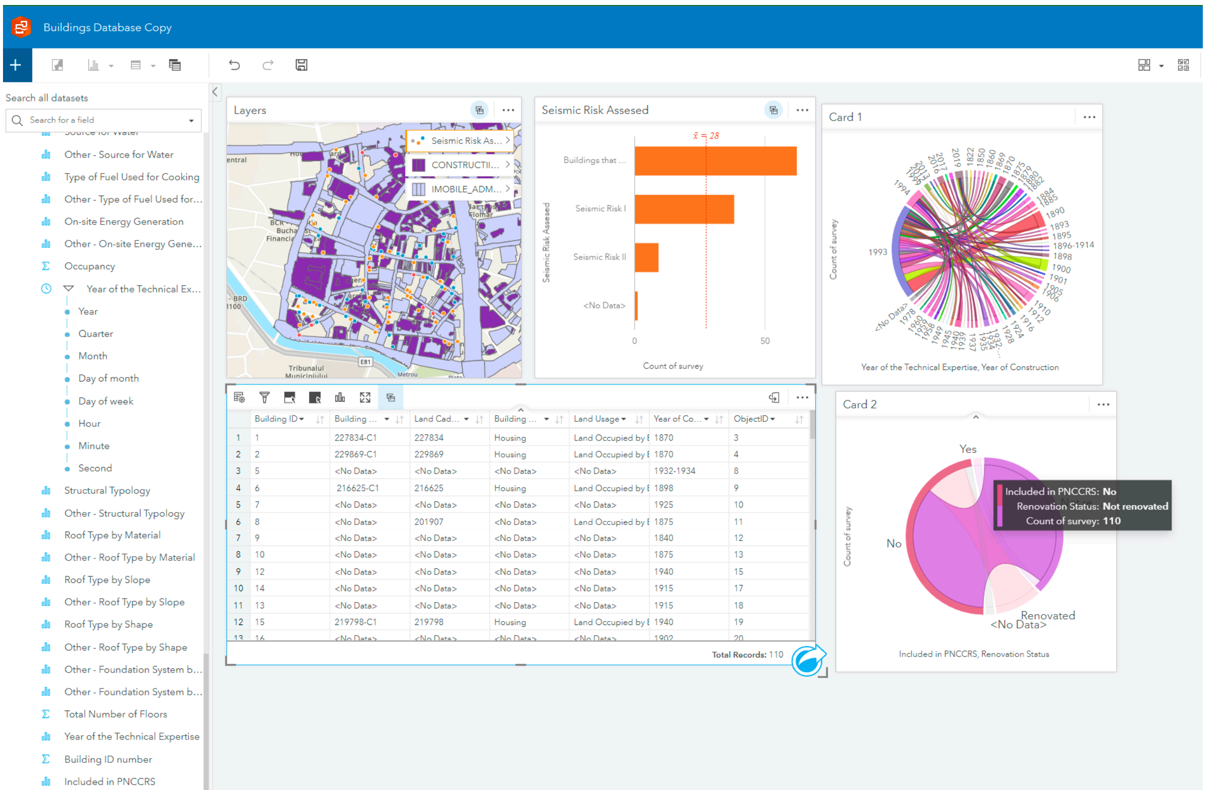


Figure 28. Buildings that were not renovated and are not included in the National Program for the Consolidation of Buildings with Seismic Risk.

The last analysis was to determine the number of buildings that were built in 1890 and are in a good condition (Figure 29), and we determined that there were four buildings that were built in 1890 and are in good condition. As more data become available, such as census data, more and more analyses can be performed.

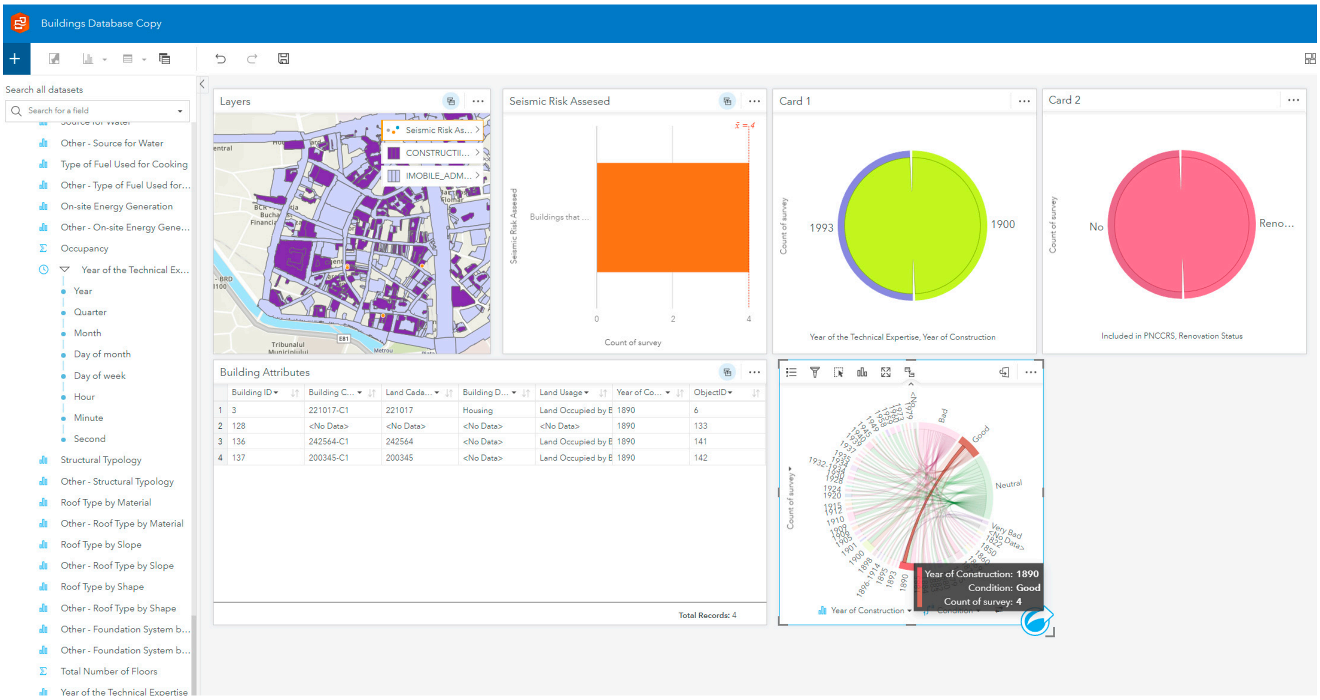


Figure 29. Buildings that were built in 1890 and are in good condition.

6. Conclusions

Creating a building database can provide a comprehensive picture of a buildings' condition, materials, structure, area, seismic risk assessed, energetic performance and destination, and plays an important role in semantic 3D city model generation. In this regard, cadastral data were integrated from the e-Terra 3 application, providing information about building's usage, number of floors or area. Data availability proved to be a limitation in this study, as the National Land Registry offers a coverage of 54.26% of the entire country, and 3D data are not available. Therefore, to determine buildings' height or roof shape, a LiDAR point cloud acquisition is necessary. An ArcGIS Survey 123 application was created in order to facilitate other data collection, such as the building's condition or renovation status, making the data collection process more efficient. Other information, such as thermal rehabilitation status, joinery type, space heating means or occupancy are needed in order to provide a better understanding of the energy performance of the building sector and to allow for energy consumption analyses.

Developing an ArcGIS Online application provides better means for data analysis and can make the results more accessible for the general public. This way, the study area can be easily explored through an interactive application. It is important to note that such an application must be based on cadastral and census data, for a better understanding of the situation regarding the affected area and population. For citizens and stakeholders, the ArcGIS Dashboard can offer a comprehensive view of the data and transparency. Using ArcGIS Insights provided the possibility to combine data analysis with data visualization, allowing us to perform and display different analyses such as the correlation between the year of construction and the year of the technical expertise, buildings that are not renovated and are not included in the National Program for the Consolidation of Buildings with Seismic Risk or buildings that were built in 1890 and are in a good condition.

After analysing the data, we observed that the largest portion of the buildings located in the studied area are either emergencies (57.72%) or seismic risk I (32.31%), and most of the buildings where usage category was available were classified as housing. Having a building database available can not only offer prompt emergency response management, but it can also contribute to better and faster consolidation and renovation planning, in order to prevent or reduce the damage caused by a major earthquake.

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Conflicts of Interest: The authors declare no conflict of interest.

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