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Procedia Structural Integrity 78 (2026) 1593–1600

Structural Integrity Procedia

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XX ANIDIS Conference

# Reliability of census data for typological identification of existing residential buildings: the case study of Bologna

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**Abstract**

In the framework of seismic risk assessment at the regional scale, the evaluation of the vulnerability of existing buildings is crucial and is generally based on the identification of structural typologies or archetypes. With reference to residential buildings, it is important to collect reliable data for a correct determination of masonry and reinforced concrete (RC) building types. In Italy, ISTAT (National Institute of Statistics) provides a wide range of datasets that are generally used as the major data source for seismic risk studies. These data, generally available as aggregate data at the census zone level, provide information about the characteristics of the buildings - such as construction age, materials, and occupancy – and allow the study of the vulnerability of these zones. The objective of this study is to evaluate their reliability through a comparison with building-by-building data. First, an on-site building-by-building investigation was conducted in a district of the city of Bologna. In this study, observed building characteristics were compared with the corresponding ISTAT data to identify divergence and assess data accuracy on the census zones. Based on these data, masonry and RC building typologies were identified and compared between the data sources. This comparison allowed to highlight, on the one hand, the importance of the survey activity, but, on the other hand, the potential use of the census data. In addition, with the objective of implementing the CARTIS methodology in the city of Bologna, both the data and the typological identification were adopted. The CARTIS form enables vulnerability analysis by contributing to the inventory of typological-structural distributions. For the CARTIS assessment, the study of the historical evolution of the city was fundamental for the creation of Sectors, along with the building features such as construction material, age, and building characteristics. The research contributes to assessing the reliability of the ISTAT data for further vulnerability assessments of residential building assets.



*Keywords:* Seismic vulnerability; Existing buildings; Census data; On-site survey; Structural typologies;

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10.1016/j.prostr.2025.12.203

## 1. Introduction

In recent years, the frequent occurrence of seismic events has made it essential to assess the vulnerability of existing buildings. The accuracy of the data gathered to analyze the vulnerability of masonry and reinforced concrete constructions within the scope of seismic risk assessment is crucial to obtain reliable results (Dolce et al. 2021). Seismic vulnerability of a building is defined as the susceptibility for a structure to display structural or non-structural damage during a seismic event (Masi et al. 2021). The vulnerability is related to building features such as the construction material, the number of floors, and the construction year, and can be described by using fragility curves, which showcase the probability of failure in relation to a specific intensity measure. There are different methods to assess the vulnerability of the existing buildings (Barbat et al. 2010). Mechanical methods are based on the execution of nonlinear numerical analyses on the building under investigation (Liguori et al. 2023; Lagomarsino and Giovinazzi 2006), while empirical methods are based on collecting real damage data from past seismic events. This empirical approach forms the foundation for more advanced seismic vulnerability assessment methodologies, which rely on statistically collected data about vulnerability factors (Zuccaro and Cacace 2015).

For the seismic risk assessment, another important factor is exposure (Vettore et al. 2020; Tocchi et al. 2022), which is defined as the number of residents and the number of buildings or, more in general, assets that could be affected by a seismic event. In Italy, for rapid data collection on ordinary buildings, the CARTIS methodology (Zuccaro et al. 2015) was developed in the framework of the ReLUIS program, funded by the Italian Civil Protection Department. First-level CARTIS form is aimed at collecting data for ordinary building typologies, such as residential buildings and service buildings, within sub-municipal areas referred to as Sectors. These Sectors are identified considering the evolution of the municipality over time and are characterized by homogeneity of the buildings in terms of construction age. For each Sector, building typologies can be defined by gathering data, through the CARTIS form, about typological features, such as construction material, construction age, number of floors, surface area, regularity, etc. Thanks to these data collection, classification of the building typologies within the urban environment can be easily performed, thus enhancing the building inventory for more developed vulnerability assessments (Polese et al. 2019).

The most widely used data platform providing access to information collected on buildings in Italy is ISTAT. It provides open access to various datasets for each municipality in Italy on a census scale (Cacace et al. 2018), which is periodically updated by ISTAT. Census zones contain several buildings with the given data, such as construction material, construction age, and number of floors. In Italy, these datasets are in use for vulnerability and exposure assessments at the regional and national levels.

The goal of this study is to verify the reliability of the census data provided by ISTAT (ISTAT 2011). Hence, the Saragozza district in Bologna has been chosen as a case study to perform a building-by-building survey, allowing for a comparison with the ISTAT data.

## 2. Description of Methodology

The methodology proposed to evaluate the reliability of the ISTAT data comprises historical research about the evolution of the city of Bologna and data collection through on-site visits. During on-site investigations, data were collected from the exterior of the buildings due to the impossibility of having access to private properties. Furthermore, post-processing of the data, i.e., all the data gathered through on-site inspections and the ISTAT data, were inserted into QGIS, which is a powerful Geographic Information System (GIS) tool to store data, visualize the data, and perform analysis. A comparison of the datasets from both the survey and ISTAT was then conducted by visualization on QGIS software. Moreover, the use of the CARTIS form improved the typological-structural building classification and allowed to identify datasets for the existing building inventory within the census zones, in order to perform vulnerability assessments on existing buildings.

### *2.1. Data Collection*

The municipality of Bologna was selected as a case study for this research. Historical research was conducted in order to understand the evolution of the city of Bologna by analyzing old maps, historical cadastral maps, and satellite images from different periods (after the XIX century). Based on these analyses, Bologna experienced its initial expansion after the 1900s, which contributed to the development of its current urban layout. By analyzing the collected documents, it was possible to see that after World War II, the city underwent the reconstruction process in some parts of its central area, which changed the historical context of the city center. These analyses displayed that during the urban development of Bologna in the XX century, the city expanded its borders in the north, east, and west directions. These studies demonstrated seven different construction periods in this time frame: before 1937, 1938-1941, 1942-1954, 1955-1964, 1965-1971, 1972-1989, and 1990-2002.

After analyzing the evolution of Bologna, the focus shifted to the Saragozza district for more detailed analyses, see Fig. 1. In this area, a total of 789 residential buildings were registered, and a total of 51 structures, such as school buildings, restaurants, etc., were excluded from the survey. Based on the historical analyses, 578 of the buildings were built before 1937, while 124 were constructed between 1938 and 1941. Additionally, 87 buildings were constructed from 1942 to 1954.

Fig. 1. Aerial photo of Bologna, highlighting the Saragozza district with orange color.

After the historical analysis of the chosen zone, on-site visits were conducted in the Saragozza district. These visits were aimed at understanding the structural characteristics of the buildings, thus, they were conducted on a building-by-building scale. During these site visits, data were collected about: address, number of stories with basements, construction material, position of typology in the urban context, plan regularity, elevation regularity, and existence of balconies. These information were categorized according to the RETURN building taxonomy, which includes the following categories: occupancy, building features, vertical structural system, building configuration, and regularity, etc. The RETURN project is an ongoing project about “Multi-risk science for resilient communities under a changing climate” and the taxonomy, which was defined for hazards other than seismic hazards, consists of attribute groups, attributes, and sub-attributes that allow to specify more detailed information. At the end of the survey, out of 789 residential buildings, 675 of the buildings were masonry structures, 109 of the buildings were reinforced concrete structures, and 5 of the buildings were mixed-material structures. The number of stories within the Saragozza district ranges between 2 and 6, and most of the buildings are isolated in the urban context. Plan regularity was evaluated considering Google satellite maps, and during the post-processing of the data, according to Eurocode 8 prescriptions.

To visualize the data and better compare with census information, they were inserted into the QGIS platform. Initially, OpenStreetMap (OSM) data were included in order to have up-to-date information about the studied area. Following this step, the dataset of each examined building was inserted into QGIS by creating a vector shapefile. The shapefile demonstrated the distribution of structures according to various data collected. Up-to-date OSM allowed the area of each building to be measured in QGIS, which enhanced the dataset created for the zone throughout the on-site investigations.

In this research, ISTAT data were also used in order to obtain information such as the number of residents, the number of buildings, construction age, and construction material for the 55 census zones identified by ISTAT in the Saragozza district. These data are reported in Table 1, with reference to both 2011 and 2021 ISTAT data. It is possible to observe that only limited information is available for the 2021 ISTAT data. For this reason, in the following, only the 2011 ISTAT data will be considered. Table 2 shows the construction period: the majority of the constructions were built before 1960, quite coherently with what was observed in the historical analysis.

Table 1. ISTAT data on the census zones of the investigated area.

| Data Source | Sections | Number of Residents | Number of Buildings | Number of Residential Buildings | Number of Masonry Buildings | Number of Reinforced Buildings | Number of mixed-material Buildings |
|---|---|---|---|---|---|---|---|
| ISTAT 2011 | 55 | 11084 | 966 | 875 | 694 | 178 | 3 |
| ISTAT 2021 | 55 | 11489 | 966 | - | - | - | - |

Table 2. Number of residential buildings for the different construction periods according to 2011 ISTAT data.

| Data Source | Construction Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Before 1919 | From 1919 to 1945 | From 1946 to 1960 | From 1961 to 1970 | From 1971 to 1980 | From 1981 to 1990 | From 1991 to 2000 | From 2001 to 2005 | After 2005 |
| ISTAT 2011 | 172 | 341 | 267 | 66 | 13 | 4 | 11 | 1 | - |

The maps shown in Fig. 2 are useful to have a general idea about the distribution of buildings and residents in the Saragozza district, according to ISTAT data.

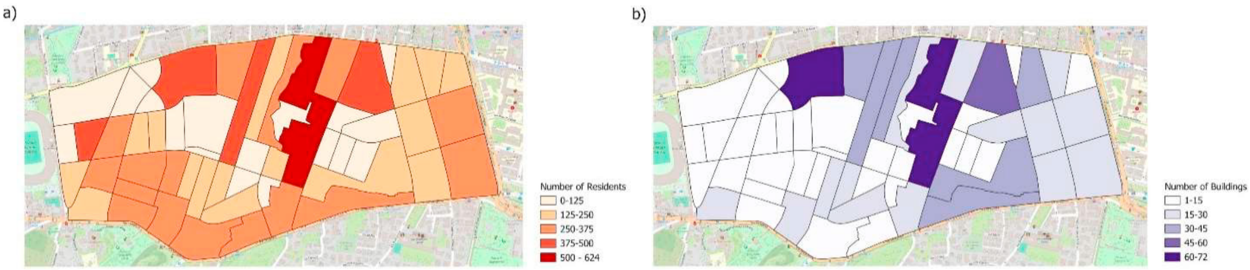


Fig. 2. ISTAT data: a) number of residents, b) number of buildings.

## 2.2. Data comparison

To carry out the data comparison between the ISTAT data and building-by-building on-site investigations, the data collected during the on-site surveys were aggregated considering the ISTAT census zones. QGIS software was utilized to perform the merge. Fig. 3 shows the number of buildings collected through on-site investigation on the census scale (the missing census zones on the map do not contain residential buildings data). There were slight differences between the two datasets. The difference between the total number of buildings is 126, and the difference between residential buildings is 86. The reason for this variation is due to the way of gathering data. The survey data were collected on the building scale, which means the focus was on the buildings themselves rather than individual civic numbers. On the other hand, ISTAT data consider the civic numbers and the dwellings.

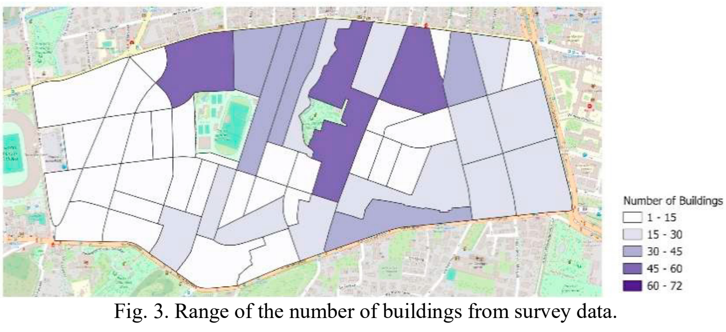


Fig. 3. Range of the number of buildings from survey data.

Fig. 4 illustrates various construction materials and their numbers according to survey and ISTAT data. The percentages displayed correspond to the total number of residential buildings for each dataset. ISTAT data registered a higher number of reinforced concrete buildings with respect to the on-site survey, while the difference between the two datasets is less for masonry structures.

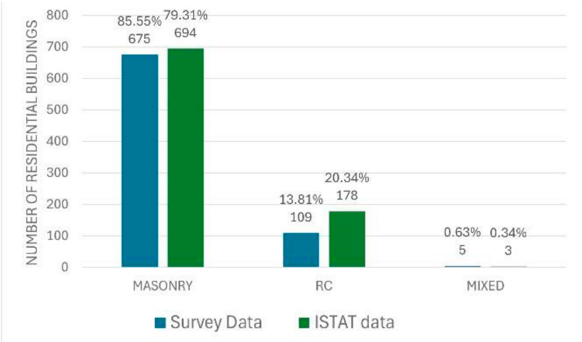


Fig. 4. Comparison between on-site survey and ISTAT data in terms of construction materials

### *2.3 Application of the CARTIS Methodology*

Given the thorough data collection during the on-site investigations, the CARTIS methodology was applied with good reliability to identify the Sectors in the Saragozza district. Initially, two approaches were applied for establishing the Sectors. The first approach was based on the construction period only, which gave as a result the identification of more than one Sector. The second approach was based on building typology as well, resulting in the definition of one Sector only. The second approach was selected for the definition of the Sector since the building types were quite similar. Once the Sector was defined, the building typologies were identified based on the construction material, number of stories, construction year (the range of the construction year was derived from ISTAT data), and surface of the building. The ranges of the data were selected directly from CARTIS form for classification of the typologies. Four different typologies for both masonry and reinforced buildings were established. In this step, mixed-material structures were considered as masonry buildings since CARTIS methodology analyzes mixed-material structures as masonry buildings. According to the CARTIS methodology, a defined sector can include a total of 8 building typologies: 4 masonry and 4 RC, and the sum of these typologies may be less than 100%, but the number of buildings that are not included in any kind of typology must not exceed 5%. Additionally, the indicated ranges of variability for the number of floors, the area, and the construction year should characterize at least 80% of the buildings included in the typology. The classification of the typologies is listed below, with notation indicating construction material (MUR for masonry and RC for reinforced concrete), ranges for the number of floors, the surface area of the building, and the construction period:

Masonry buildings (MUR) typologies:

- MUR1: 2-6 / 70-170 / 1946-1970
- MUR2: 2-6 / 230-650 / 1946-1970
- MUR3: 2-6 / 230-650 / 1900-1945
- MUR4: 2-6 / 70-170 / 1900-1945

Reinforced concrete building (RC) typologies:

- RC1: 9-11 / 500-1200 / 1946-1970
- RC2: 6-8 / 500-1200 / 1946-1970
- RC3: 6-8 / 130-400 / 1946-1970
- RC4: 3-5 / 130-400 / 1946-1970

The majority of the buildings are masonry structures. MUR1 represents medium-rise buildings with a small surface area that were constructed after World War II, which feature rectangular, vertically aligned windows and a regular elevation. MUR2 is the typology of medium-rise buildings above ground, featuring vertically aligned symmetrical openings that were constructed after the war. They have small balconies, and the ground floor is low-rise. MUR3 stands for medium-rise buildings with an attic, which were constructed before the 1945s. The openings are symmetrical and vertically aligned, however, the ground-level openings are wider. MUR4 displays medium-rise buildings with vertically aligned openings, which were constructed before the 1945s. Fig. 5 represents the distribution of the masonry building typologies within the Saragozza district. Among these typologies, the most common types are MUR3 and MUR4, indicating that the majority of the Saragozza district was built before 1919 and from 1919 to 1945. The buildings generally have a small surface area, with the number of floors ranging from 2 to 6.

As for the RC typologies within the Saragozza district, all the RC buildings were constructed after the war. RC1 is high-rise buildings with a big surface area, which have vertically aligned rectangular openings with balconies, sometimes featuring an irregular elevation due to absence of infills at the ground floor. RC2 represents medium-rise, big surface area buildings with vertically aligned openings and balconies. RC3 demonstrates medium-rise, small surface area buildings with vertically aligned openings and balconies with a regular elevation. RC4 stands for low-rise buildings with vertically aligned big openings and balconies with an irregular elevation. It is the most common typology within the area. Fig. 6 represents the distribution of the reinforced concrete building typologies within the Saragozza district. Overall, in the zone, RC buildings are predominantly constructed before the 1960s, and only a few of them have a large floor area and a higher number of floors with respect to the ranges considered in the classification.


| Typology | N.of Buildings | Percentage |
|---|---|---|
| MUR1 | 67 | 8,5% |
| MUR2 | 118 | 14,9% |
| MUR3 | 213 | 27% |
| MUR4 | 255 | 32,3% |
| OTHER | 26 | 3,3% |

Fig. 5. Masonry building typologies in the Saragozza district (percentages are referred to the total number of residential buildings).


Fig. 6. RC building typologies in the Saragozza district (percentages are referred to the total number of residential buildings).

## 3. Conclusion

The need to mitigate the loss of human life and the occurrence of damage and collapse of structures during a seismic event makes it crucial to perform vulnerability assessments of urban areas. The open-access ISTAT data are commonly used in Italy for characterizing the exposed assets and identifying structural classes for which fragility curves are available. The goal of this study was to evaluate the reliability of the ISTAT data, which are usually available in an aggregate form at the census scale level, through on-site investigations on a district of the city of Bologna. Furthermore, thanks to the collected data, the CARTIS methodology could also be applied with the aim of identifying structural typologies based on specific data collection.

The result of the comparison of both datasets shows a minor variation in the total number of buildings and the construction material of the buildings due to the different data collection methodology. ISTAT gathered data based on dwellings and civic numbers, while the survey collected data based on buildings. Yet, ISTAT data shows compatibility with the examined data.

With the CARTIS methodology, one Sector is defined based on structural typologies of the Saragozza district. Within the Sector, four masonry (MUR1, MUR2, MUR3, MUR4) and four reinforced concrete (RC1, RC2, RC3, RC4) building typologies were defined. According to this classification, the dominant structural typology of the district is masonry.

As a result, the compatibility of the ISTAT data with surveyed data and the development of the datasets through the CARTIS methodology provide more accurate and reliable data for future vulnerability and exposure assessments. Based on the correspondence between the survey and ISTAT data, the CARTIS methodology could be applied in the future to the entire city of Bologna, using ISTAT data with a limited number of on-site investigations.

## Acknowledgements

This study received funding from the European Union NextGenerationEU and was carried out in the framework of the project PNRR RETURN (National Recovery and Resilience Plan—NRRP, Mission 4, Component 2, Investment 1.3—D.D. 1243 2/8/2022, PE0000005). The financial support of the Italian Department of Civil Protection (ReLUIS 2024-2026 Grant-WP4) is also gratefully acknowledged.

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