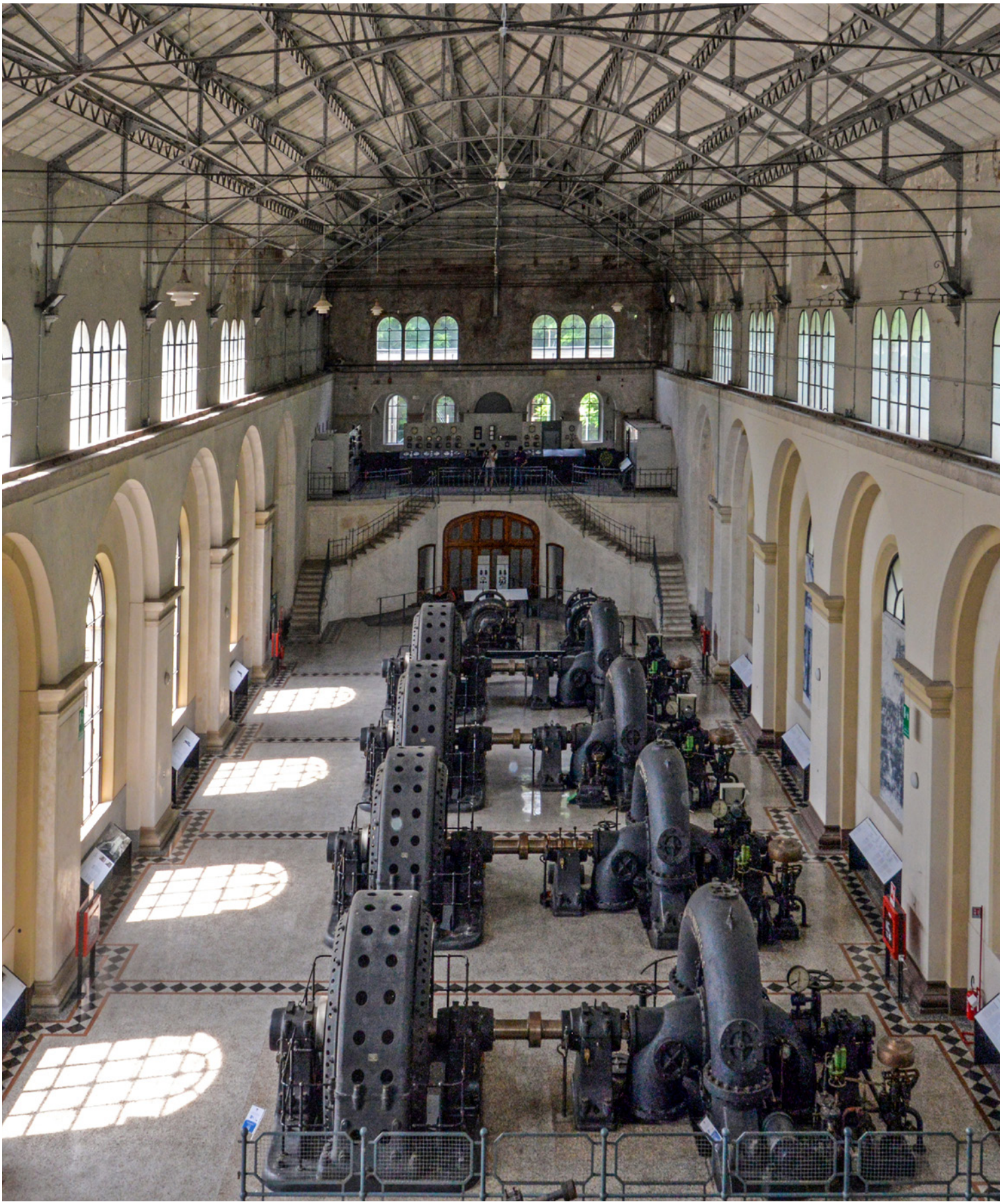

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DIGITAL GEOREFERENCED ARCHIVES: ANALYSIS AND MAPPING OF RESIDENTIAL CONSTRUCTION IN BOLOGNA IN THE SECOND HALF OF THE TWENTIETH CENTURY

Anna Chiara Benedetti, Carlo Costantino, Riccardo Gulli

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Highlights

Digital archive for the housing sector in Bologna in the second half of the twentieth century using GIS software. Implementation of a municipal georeferenced database with data about buildings from construction permits consultation and representation in a georeferenced map. Targeted queries and analyses on a georeferenced database of residential heritage for mapping the urban territory. Selection processes to identify specific parts of the urban area using GIS software.

Abstract

The study is aimed to provide a detailed knowledge database of the housing sector in the period of real estate significant expansion in Bologna in the second half of the 20th century. The final objective is the definition of a digital archive that is accessible and searchable and also a tool for analyses before interventions. The first phase of this research has focused on consulting cartographies and archival documents. On the one hand, analyzing maps and aerial photos of Bologna has identified the urban sprawl in the reference period 1940-1970. On the other hand, the cataloguing from new building permits provides some relevant data about architectural and construction features of the housing sector in the same period. The data resulting from archival research are implemented with a municipal georeferenced database using GIS software. In this way, a direct link is created between building specificities, urban fabric, and localization, so that the shifting from the urban scale to the building one is always possible. Then, another purpose is the definition of an algorithm to identify a sample of residential lots suitable for replacement within the urban perimeter of the city up to 1970. An evaluation method is currently ongoing to assess the convenience of this intervention category, rather than restoration, and to define a protocol to support the decision-making process together with a management system in three areas (technical, social, and economic) respecting circularity.

Keywords

GIS software, Digital archive, Residential heritage, 20th century, Bologna.

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1. INTRODUCTION

The Italian construction history can be summarized with reasonable approximations by four periods, based on regulatory issues: (i) up to the 19th century, when almost the totality of masonry constructions was built, without going into detail about the wide variety of vernacular forms or techniques; (ii) the first half of the 20th century, when the extensive use of masonry load-bearing structure coexists with the first experimental applications of the reinforced concrete frame structure; (iii) the second half of the 20th century up to the definition of the national regulatory framework about structural and fire safety, energy consumption, removing architectural barriers, etc.; (iv) the contemporary constructions built in the last twenty-five years, since the above-mentioned regulatory framework was established. The most of existing dwellings were built before the 1970s as a direct consequence of the population growth following welfare dissemination in accordance with economic recovery and industrialization processes after the Second World War. Moreover, comparing this chronological division with functions (housing, administrative, tertiary, commercial, industrial, services, infrastructures, religious, etc.) and with property (public and private), the complexity of building heritage is clearly highlighted.

Identifying the construction period and the choice of building use is necessary for elaborating a targeted proposal that can be effectively applied to the existing heritage. The research is focused on the housing constructions built in the period 1946-1965, herein considered a representative sample of the buildings that do not respect current regulatory standards [1] and require high-impact interventions according to cost-benefit analysis, engineering optimization, and economic sustainability. Indeed, most of the dwellings were realized during the housing sector's strong expansion, which is a period marked by a lack of regulatory framework in terms of structural and fire safety and energy performance. Then, almost all residential constructions built in 1946-1965 in Italy do not meet the minimum criteria laid down in the regulation and have structural deficiencies that are

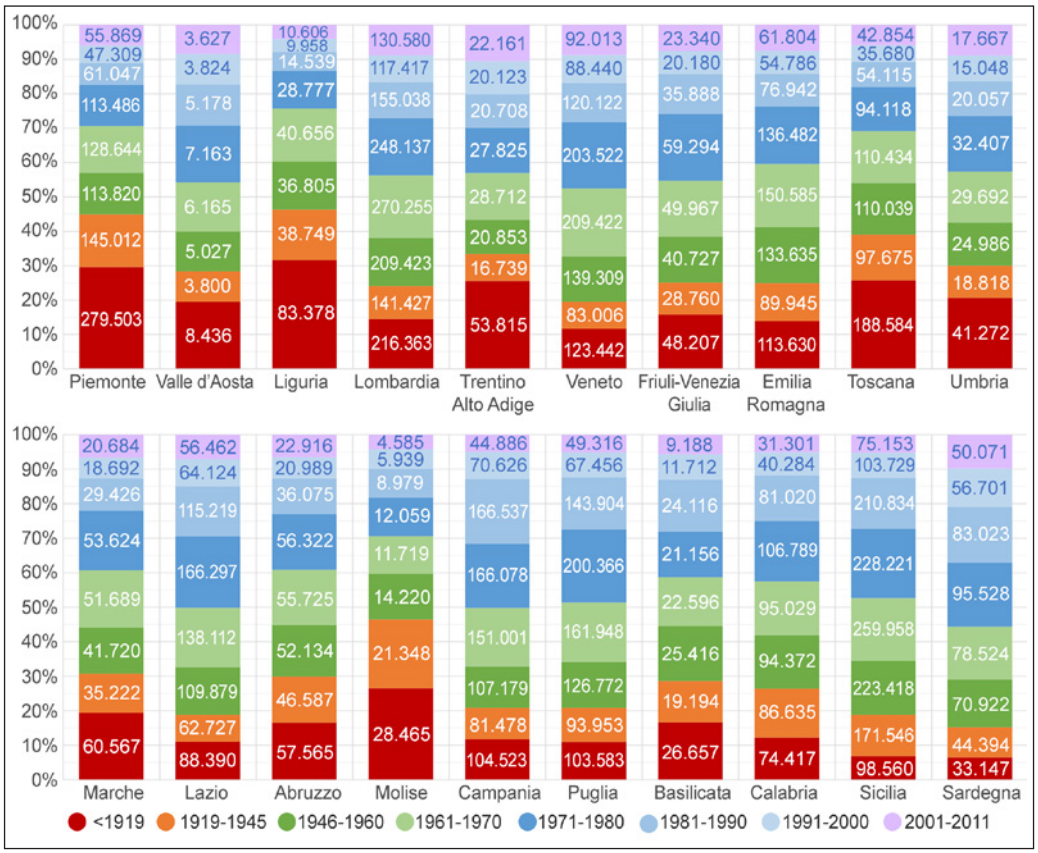

Fig. 1. *Residential buildings (absolute values) in regions according to ISTAT construction periods (data from 15th Italian Census) © 2020, Author.*

not suited, due to their constitutive nature, to be solved with sustainable renovation measures in economic and technical terms. The same situation concerns energy refurbishment interventions; in fact, except for insulating envelopes and windows frames replacement, the more innovative solutions interest plants and facilities.

From the last Italian census data [2], most buildings were constructed during the period 1945-1990, and they represent 60,2% of the totality of existing residential constructions in Italy, while only 10,9% was realized in the period 1919-1945, 15% before 1919 and 13,9% from 1991 up to 2011. More specifically, during 1945-1990, the ISTAT has reported an increase of +7.332.087 residential buildings (+1.700.836 in 1946-1960 and +2.050.883 in 1961-1970, respectively 14% and 16,8% of the housing heritage. However, the Italian territory presents very heterogeneous data as a direct consequence of a non-uniform development (Fig. 1).

The findings on the municipal area of Bologna confirm the choice of 1946-1965 as the period of the most significant expansion of the construction sector for the city, with an average construction rate r_C equal to 376 buildings residential per year. The construction rate r_C is calculated as the ratio of residential buildings divided by the number of years for each interval, excluding buildings prior to 1919. The rate for the interval 1946-1965 is calculated as the arithmetic average of the rates for the periods 1946-1960 and 1961-1970. The results are listed below (Tab. 1).

Moreover, 43,1% of the existing dwellings in Bologna was built in 1946-1970, and it consists of +9.656 units, while 20,7% dates before 1919; 21,4% in 1919-1945; 11,5% in 1971-2000 and only 2,85% in 2001-2011.

In this first phase, the considerations resulting from ISTAT data are a support element for the selection of the reference period as well as a basis for comparison during the methodology formulation of a georeferenced database for the building heritage. Nevertheless, this data is not sufficiently reliable and accurate for developing the database mentioned before, as evidenced by the comparison between the ISTAT data and the analysis of city expansion obtained with the overlapping of maps and aerial photos (Fig. 3). For this reason, the archival data on construction permits and the direct comparison of geographic information in ArcGIS allows identifying more accurately the urban perimeter of the city in 1971, excluding areas built after 1971, those demolished and rebuilt after 1971, and not built in 1971 that nowadays.

2. METHODOLOGY AND OBJECTIVES

The methodology herein proposed aims, on the one hand, to the formalization of a solid knowledge database for the building heritage that can be effectively used and query for many evaluations about existing constructions state of conservation, and a decision support tool during the planning of interventions as well as a base for future research development. On the other hand, it points to recognising of some areas within the urban territory of towns and cities that can be interested in more radical interventions than structural restoration and energy refurbishment. In fact, the final objective is to define of a system for interventions management that prefers replacement, namely demolition with reconstruction, in respect of environmental sustainability and processes circularity.

	< 1919	1919-1945	1946-1960	1961-1970	1971-1980	1981-1990	1991-2000	2001-2011
Years [No.]	-	27	15	10	10	10	10	11
New buildings [No.]	4,587	4,730	6,434	3,222	1,305	587	652	632
New buildings [%]	20.71	21.36	29.05	13.96	5.89	2.65	2.94	2.85
Construction rate r_C = New buildings [No.] per year	-	175	429	322	131	59	65	57

Tab. 1. *Average construction rate in the different chronological intervals based on ISTAT data of the 15th General Census of Population and Housing (2011) for the Municipality of Bologna © 2020, Author.*

2.1. ARCHIVAL RESEARCH AND GEOREFERENCED CITY MAP

Starting from the period after the Second World War, the city of Bologna has met a wide expansion following the main road axis. The consulting activities of maps, cartographies, and aerial photographs at the *Archivio di Stato* of Bologna and Municipality SIT *Sistemi Informativi Territoriale* office, has been necessary to outline in a qualitative way the urban sprawl and identify the main directions of the city development in the surroundings in the period 1920-1971, according to 5-7 years time intervals. In particular, the maps of the city in 1920-21 (*Quadro d'Unione* Union Framework of the city of Bologna, at *Archivio di Stato*), 1941 and 1949 (Cartography of Bologna and Urban Cadastre at Municipality of Bologna); the aerial photographs of the city in 1944, 1954 (property of I.G.M., Military Geographic Institute) and in 1959, 1964 (property of C.G.R., *Compagnia Generale Ripreseaeree S.p.A.*) and 1971 (property of R.E.R., *Regione Emilia-Romagna*) have been accessed by paper means or by electronic means [3]. Comparing and overlapping maps and aerial photographs highlights the perimeter of the urbanized area in 1970-71, that is also this research study area (Fig. 4), whose borders were defined by natural and artificial elements too, i.e., rivers and elevations, high-speed roads, etc.; we have motorway and orbital road in the North, Bolognese hills in the South, river Savena in the East and river Reno in the West.

On the other hand, archival research on constructions permits filed in *Casellario Abitazioni* at the His-

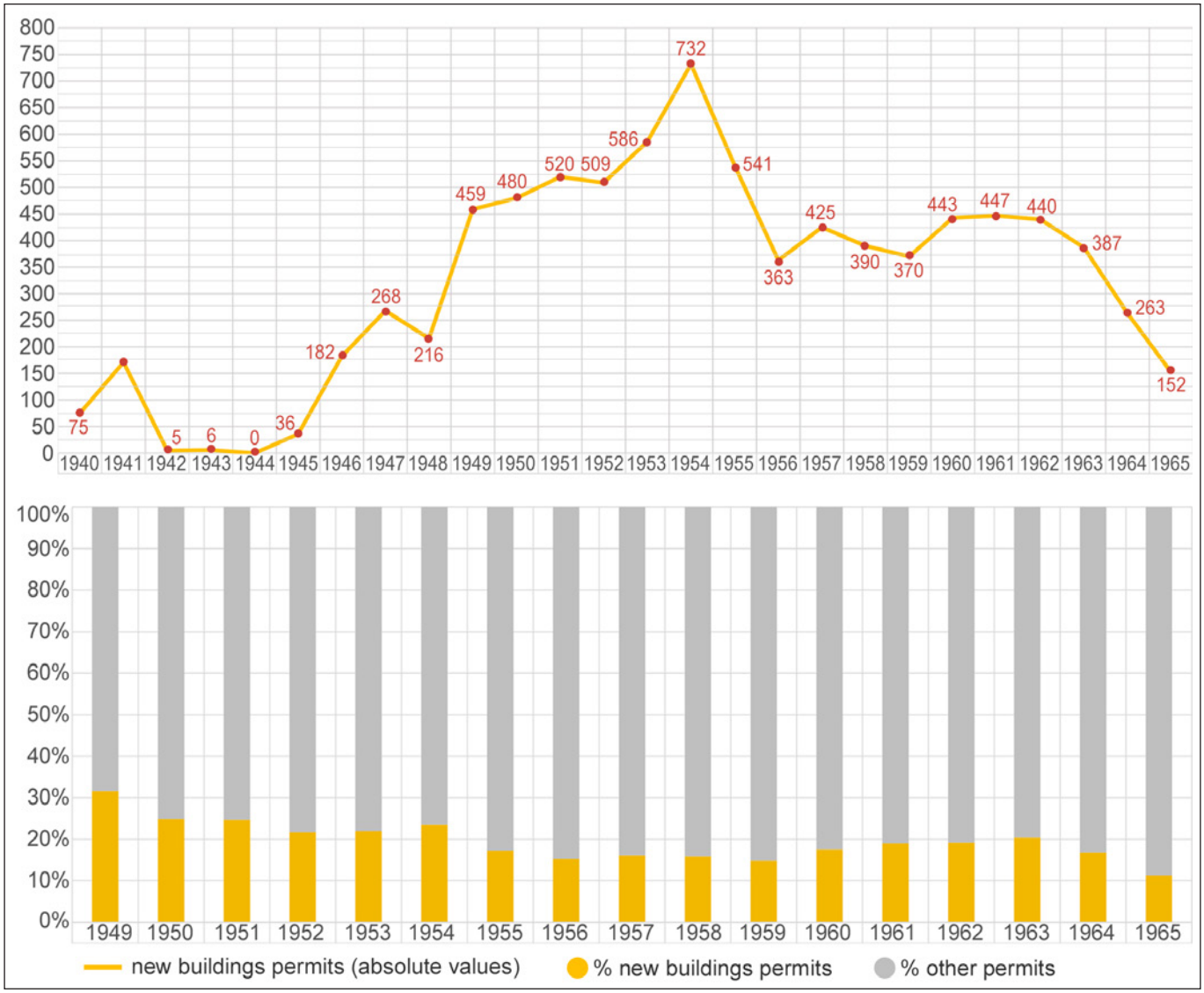

Fig. 2. *Analysis on building permits during 1940-1965 in Bologna (data from archival documents) © 2020, Author.*

toric Municipal Archive (1946-1948) and SUE *Sportello Unico per l'Edilizia* Digital Archive of the Municipality (1949-1965), provides some relevant information about the year of construction, architectural structural and dimensional specifications of residential buildings in the second half of the 20th century. During the period 1946-1965, 8.173 building permits for new constructions or reconstructions have been deposited in the municipal offices, with an average of 409 new permits per year. Starting from 1945, the Municipal Administration has promoted the *Piano di Ricostruzione* (Reconstruction Plan) to recover destroyed areas by Second World War bombings; the plan was authorized on November 30th, 1946, and the final approval was on January 16th, 1948 [4]. In 1949, thanks to the writing of the New Urban Cadastre, together with the recovery plan, the construction sector registered a relevant increase, and the number of new residential buildings realized in 1949 was twice that of previous years, showing a growing trend up to 1962 (Fig. 2).

Further analysis shows that the number of new buildings and reconstruction practices constitutes about 19.4% of the entire building permits (extensions, additional storeys, internal restorations, etc.). The average percentage is calculated as the ratio of the number of new construction and reconstruction interventions in the urban territory, equal to 7,507, and the totality of building permits equal to 38,711 in the period 1949-1965. The data for the years 1946-1947-1948, prior to the post-war reconstruction, are excluded because they are considered not very representative as they are affected by the emergency situation of the period after the Second World War. In addition, a second value equal to 19.5% confirms the validity of the first one. This is obtained from the arithmetic average calculation, namely, the ratio of the sum of the values expressed as a percentage of the new construction and reconstruction interventions per year and the reference period's number of years, which are 17 (Tab. 2).

These simple analyses were carried out by crossing the number of building permits with the chronological datum shows that the new buildings are about 1/5 of the total during the reference period 1946-1965. Furthermore, the variation in terms of absolute values of new constructions or reconstructions is characterized by an increasing trend up to 1954, then it settles on values comparable to 1949 ones, and finally decreases significantly from 1962-1963. The study on building permits at the Historic Municipal Archive (1946-1948) and SUE *Sportello Unico per l'Edilizia* (Municipal Digital Archive) remarks the considerations that emerged from the statistical analyses

Year	Constructions reconstructions absolute values [No.]	Other interventions absolute values [No.]	Percentage of constructions reconstructions [%]	Year	Constructions reconstructions absolute values [No.]	Other interventions absolute values [No.]	Percentage of constructions reconstructions [%]
1940	75	-	-	1941	171	-	-
1942	5	-	-	1943	6	-	-
1944	0	-	-	1945	36	-	-
1946	182	-	-	1947	268	-	-
1948	216	-	-	1949	459	1,455	32
1950	480	1,930	25	1951	520	2,105	25
1952	509	2,349	22	1953	586	2,670	22
1954	732	3,124	23	1955	541	3,126	17
1956	363	2,382	15	1957	425	2,638	16
1958	390	2,458	16	1959	370	2,492	15
1960	443	2,524	18	1961	447	2,350	19
1962	440	2,294	19	1963	387	1,901	20
1964	263	1,566	17	1965	152	1,965	11

Tab. 2. *Percentage of the new construction or reconstructions interventions per year, based on data from building permits collected at the Historic Municipal Archive (1946-1948) and SUE Sportello Unico per l'Edilizia (Municipal Digital Archive, 1949-1965 © 2020, Author.*

on residential buildings data provided by ISTAT, according to which the period with most intense construction activity is 1946-1960, with an average annual construction rate r_C of 422. It is important to note that the number of unauthorized interventions (subjected to denial) has been removed from new constructions one. Moreover, it is feasible to envisage that the number of constructions is not very different from the number of building permits because some interventions, already authorized, have not been built due to unexpected circumstances, and at the same time, one permit may concern the construction of more than one building. While considering a large number of data, the resulting deviation does not affect the reliability of the outcomes for future developments.

The building permits have been collected and catalogued using a standard spreadsheet program (Excel). This table provides some relevant data about architectural and construction features, i.e., building type, load-bearing structure (masonry, reinforced concrete or steel frame structure, mixed), number of floors at the construction, the presence of basement and habitable or non-habitable roof-space, protocol code numbers and year, if the interventions were promoted by social housing institute; references to location (address, district) and other secondary information, such as the property and the designer (architect, engineer, technical surveyors). Building types are defined as "all those housing solutions […] that are characterized by a plan layout, a specific relationship between the building units and numbers of floors" (original Italian quote: "tutte quelle soluzioni dell'alloggio […] che si differenziano per la disposizione planimetrica degli elementi che lo compongono, per il sistema associativo delle singole unità di abitazione e per il numero di piani") [5]. These are identified by visual analysis of documents already collected. After an initial distinction of single-family houses (S) and multi-storeys buildings (P), the following types are assigned [6], [7]: (I) isolated building; (R) row houses; (OB) multi-story open block building; (DA) deck-access block; (HR) high-rise apartments building; (CB) multi-story closed block building. Regarding structural frame and construction material, the following categories are identified: (RC) reinforced concrete frame structure, consisting of pillars and floor beams in reinforced concrete; (M) massive masonry structure with load-bearing brick walls; (S) steel frame structure consisting of steel pillars and beams; (MRC) mixed structure, characterized by the coexistence of pillars and beams in reinforced concrete and load-bearing walls in masonry. Therefore, based on the previous considerations, each residential building is defined by a series of descriptive attributes (number of floors, year of construction, PG, PUT, if the intervention was promoted by social housing institute, client, designer, and/or construction manager) and from a set of letters that identify the typological and construction characteristics, for example (SI) and (M) if a single-family house with a massive load-bearing masonry structure. Furthermore, during the consultation of the building practices, the location data of the intervention are collected: street name and number (at construction or current) and the building identification code. This information is the key for the association between the attributes of the cataloging table of building permits and the georeferenced databases available online on the website of the municipal administration of Bologna [8].

The collection of archival documents is necessary to obtain a detailed overall report of structural, architectural, and spatial characteristics of all the residential buildings, and this can implement territory analysis on maps.

Using the GIS software ArcGIS (Esri), the representation of the city building heritage is then associated with many analyses displayed as the result of querying georeferenced database currently available on the websites of the Municipality of Bologna and ISTAT, and data from the cataloguing table. Overlapping maps and aerial photographs for the definition of the perimeter of the urbanized area in 1971 and the study area is recreated in a georeferenced map of the city using the GIS software. Moreover, as the time intervals of aerial photographs and charts are the same as ISTAT construction periods, the direct comparison between these two sources is clearly displayed using the software.

This mapping of the urban territory with five different colours, each corresponding to a single time interval, has led to distinguishing the areas with a majority of: residential buildings prior to 1919; residential buildings built between 1919 and 1945; residential buildings built between 1946 and 1970; residential buildings built between 1971 and 2000 and built after 2000 [9]. The re-

quirement used to divide the area in these chronological ranges is the presence of a percentage greater than 50% of buildings built in the same period compared to the overall buildings that are in the same census section, i.e., the smallest territory part in which the municipality is subdivided during the census survey, as well as a reference source with respect to which the absolute values of the number of residential buildings by construction period are available (Fig. 3).

The comparison of the mapping based on ISTAT data with the map of 1920-21 and the aerial photos of 1944 and 1971 confirmed the low reliability of the records of the building census. Indeed, some census sections do not belong to the correct period. However, the cross-comparisons between data and maps allows identifying the perimeter of the urbanized territory in 1971 using the European Datum 1950 UTM Zone 32N geographic coordinate system (Fig. 4), and also the area where buildings dating back to 1946-1970 prevail, with an acceptable degree of confidence, as the aerial photos certainly show an accurate view of the city.

The study area is divided into a homogeneous zones network, consisting of 7 districts and 205 cadastral sheets, in order to link analysis on buildings data, which have been collected, to the urban territory. The districts, resulting from an editing of the current municipal division, are identified as zone 1 *Centro Storico* namely Historic Center, zone 2 *Costa-Saragozza*, zone 3 *Porto-Tanari*,

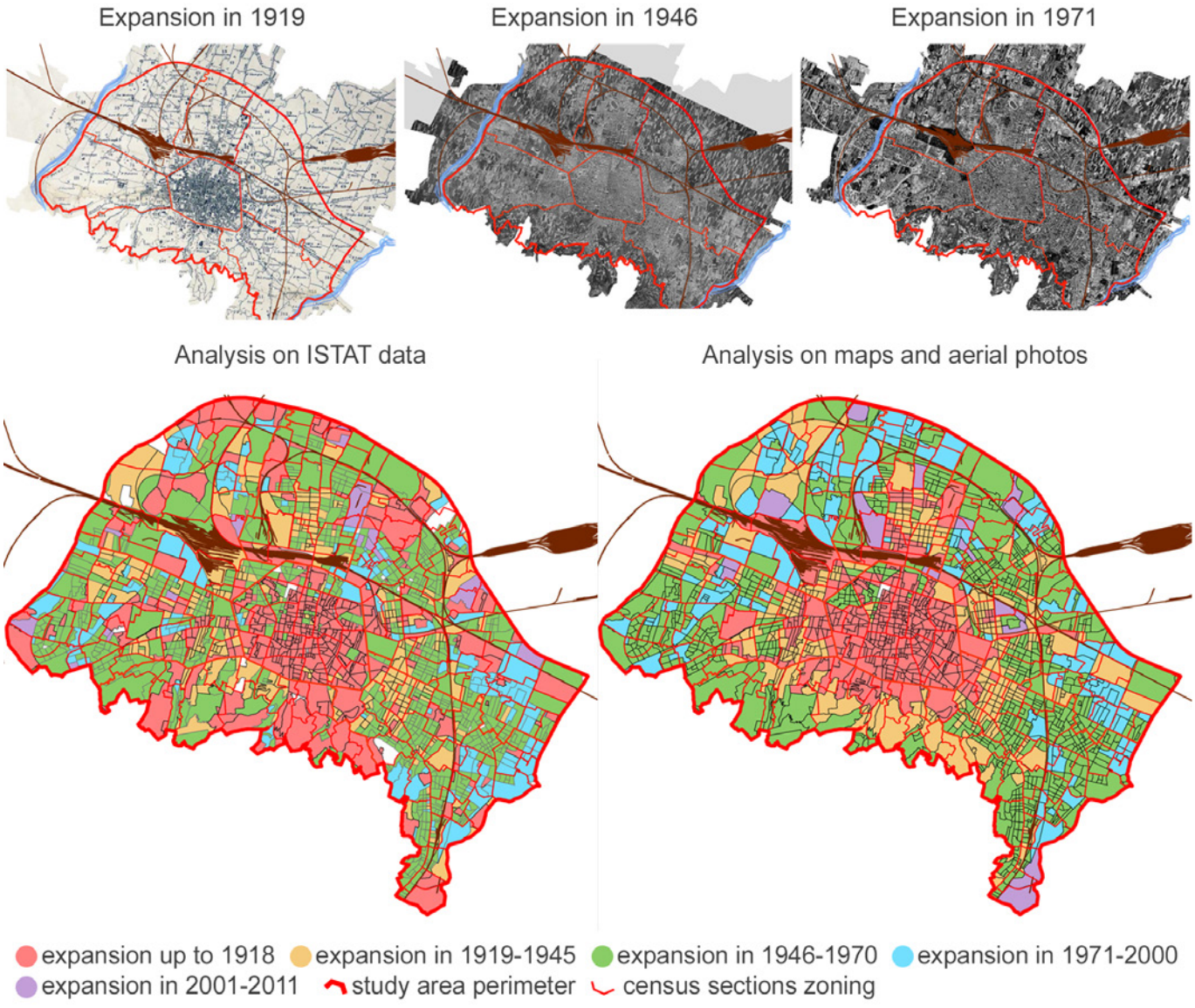

Fig. 3. *Reconstruction of the city expansion by comparing ISTAT data (number of residential buildings in reference periods) and the reconstruction of the urban sprawl obtained by overlapping maps and aerial photos with a GIS software © 2020, Authors.*

zone 4 *Bolognina*, zone 5 *San Donato-Cirenaica*, zone 6 *Città Giardino-San Ruffillo* and zone 7 *Colli*. These sectors are parcelled out in cadastral sheets; there are 19 sheets in zone 1, 30 in zone 2, 28 in zone 3, 25 in zone 4, 46 in zone 5, 37 in zone 6, and 20 in zone 7 (Fig. 4).

A georeferenced municipal technical map is obtained by using a software GIS and georeferenced database from the Municipality of Bologna. This first map includes many layers of information: buildings, streets, infrastructures, watercourses, green areas and trees, other urban and natural elements, etc., that are overlapped with the division in seven districts and cadastral sheets. This georeferenced map of Bologna has been implemented and updated with current urban planning regulations, such as constraints and protections on territories and buildings, PSC *Piano Strutturale Comunale* (Municipal Structural Plan) areas division then replaced by the PUG *Piano Urbanistico Generale* (General Urban Plan) one [9]. This georeferenced map connects information about the urban territory and building heritage, and the access to global results as well as specific ones is possible using of simple and various queries so that the shifting from the urban scale to the building one is always available.

2.2. THE DEFINITION OF AN ALGORITHM FOR THE SELECTION OF URBAN AREAS

The definition and application of a detailed sequence of actions (mathematical operations and objective conditions) are herein intended to perform a specific task: the individuation of a sample of urban blocks that can be potentially suitable for more radical interventions on ex-

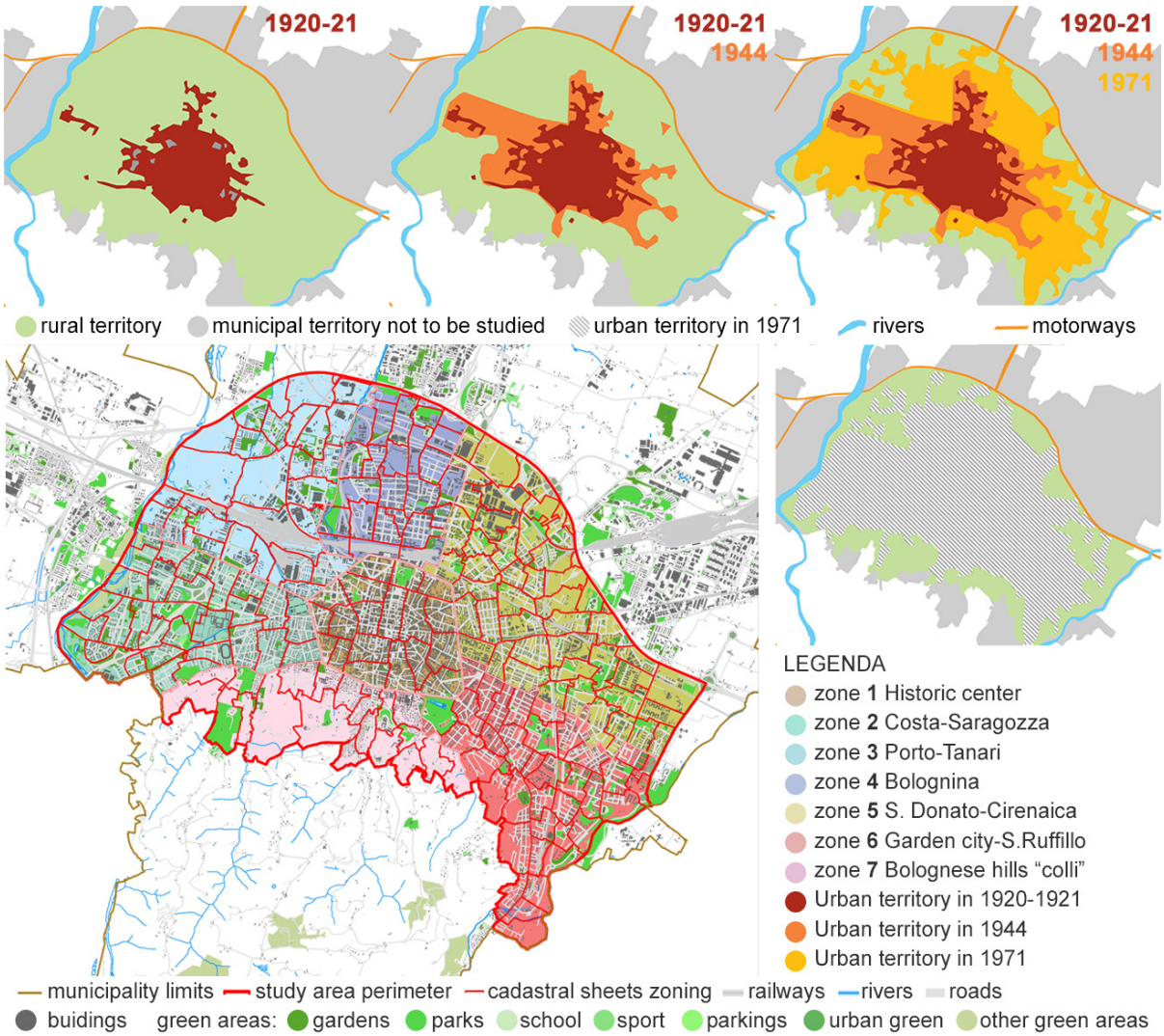

Fig. 4. *Map with the urban sprawl representation in the period 1920-1971 and the division of the study area in districts and cadastral sheets © 2020, Authors.*

isting buildings, including replacement. At present, the selection procedure has been tested in the georeferenced map and, firstly, are excluded restricted areas.

More specifically, the first part of the selection algorithm, intended as a sequence of exclusion actions, is defined by the following conditions: (0) exclusion of the territory outside the perimeter of the study area and creation of the first sample of urban areas by subtracting streets surfaces; (1-2-3) exclusion of three different groups of restrictions regarding territory (infrastructures, cemeteries, natural areas, protected and relevant river zones, specialized green areas = vincoli 01), buildings (building aggregated of historical and architectural interest, and of cultural and testimonial interest of the second half of the twentieth century, zone subjected to indirect protection prescriptions according to article 45, Legislative Decree 42/2004, historical and urban relevant zones = vincoli 02) and local General Urban Plan (historic urban fabric: antique formation centres, garden districts, historic specialized areas, historic urban compact fabric = vincoli 03).

The territory sample resulting from the elimination of the areas mentioned before is then intersected with parts of the city (i) to regenerate, (ii) that are planned with urban implementation instrument, and (iii) to be completed (according to the PUG). The sample of 880 elements is the result of some spatial and mathematical operations using merge, clip, symmetrical difference, and intersection commands in Analysis Tools in ArcToolbox, so the first sample of urban areas is obtained.

The following part of the selection procedure considers the chronological aspect: 1971 aerial photographs have been georeferenced and overlapped with the first 880-elements sample and are manually excluded all the areas that were built after 1971 or demolished and reconstructed after 1971 and not built ones in 1971 up to 2021.

The result of this set of actions is the second group of 670 areas that have varying surfaces between the minimum 823.31 sqm and the maximum 197.590,34 sqm. Then, all the areas with a territorial extension smaller than 8,000 sqm are excluded; in fact, these are not suitable for planning replacement interventions that can be effectively sustainable in terms of optimization and quality as end spaces in already removed areas. The result is a third group consisting of 304 areas. It is important to note that this 304-areas sample initiates a shift from urban dimension to building one, as far as the selection procedure has been carried out in territorial size. In this phase, the areas with specialized buildings (hospitals, school buildings, churches, and towers) which are incompatible with mostly residential replacement interventions, and low-built areas, which do not respect demolition with reconstruction requirements, are excluded. In the following phases, the reference 304-sample is implemented with much data about the constructions and is further selected on the basis of analyses on the building size in accordance with the objectives of this research. More specifically, the 304-areas sample is completed with the ratio of area coverage by listed buildings and factories and the total territorial surface, so that are removed from the sample all the areas where the value of coverage is greater than 20% and constitutes a restriction for the replacement intervention. The sample is so reduced to 173 areas that are currently analyzed and examined more closely. This process has produced the first sample of parts of the municipal territory that are effectively geolocalized and can be further studied in the following steps of this research.

3. RESULTS

As already stated, the result of the selection process is a group of urban blocks where demolition with reconstruction is affordable, respecting the current urban planning regulation and the national and regional regulatory framework. Using some specific criteria (absence of specialized buildings, surface coverage by listed building and factories minor than 20%, and exclusion of low-built areas), 173 georeferenced areas are obtained, namely with an extension greater than 8,000 sqm, largely residential, with no constraints, built in the reference period 1946-1970, and are divided into the 7 districts: 0 in zone 1, 0 in zone 7, 11 in zone 3, 23 in zone 4, 36 in zone 2, 51 in zone 5 and 52 in zone 6 (Fig. 5).

Also, using ArcGIS software, a direct and unique link is created within the building attributes of the cataloguing table and the georeferenced polygon in the map by means of the identification of an alphanumeric code, obtained by the union of specific codes for house number, house sub number and building number (named “CIVICO_SUB-

CIVICO_CODEDIF") that is available both in the cataloguing table and georeferenced municipal database on GIS software [8]. In this way, polygons in the georeferenced map, which already include all the geometric information, are implemented with the other one collected in the spreadsheet, and this new database can be used for targeted queries, visualizing specific results to support urban planning and research on building heritage, and shifting from urban scale to the building one is always possible. The data association herein described is a complex operation that has to be verified to ensure reliable results. So far, it has been tested in a representative sample of buildings located in 12 areas out of 173, in order to identify weaknesses and mistakes and progressively extend the association to all the buildings of the sample. The ArcGIS model is then implemented with a three-dimensional environment using ArcGIS Pro (Fig. 5).

Analyses on construction and architectural characteristics on buildings and dimensional and morphological ones on lots are ongoing to obtain some representative values of planning parameters [10, 11], (F.A.R. Floor Area Ratio, building and population density, GSI, Ground Space Index or Coverage, etc.) that can be used prior to the intervention (Fig. 5).

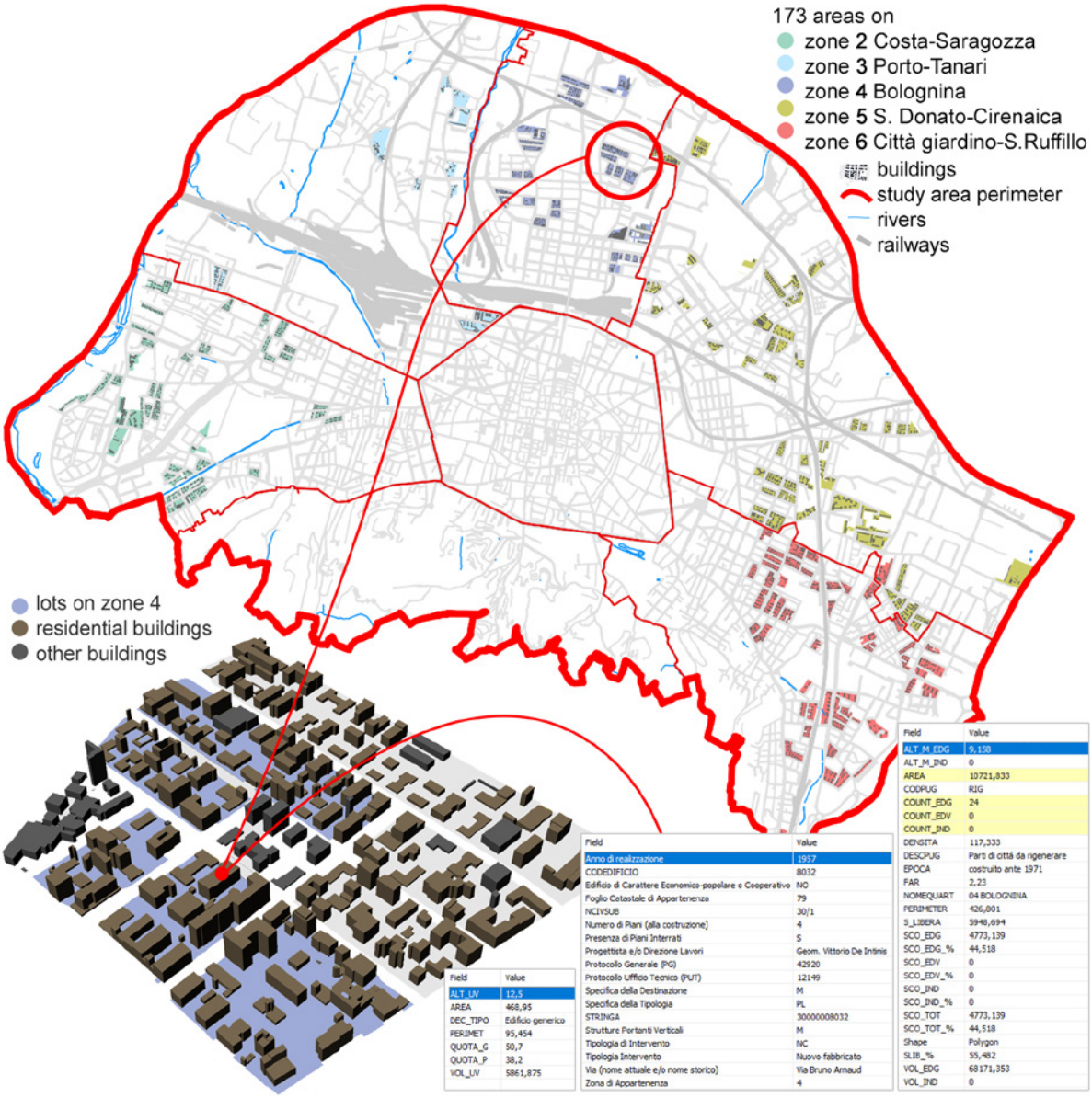

Fig. 5. *Mapping of municipal territory of Bologna using the GIS software ArcGis by Esri, with the indication of the sample of 173 areas suitable to replacement interventions, respecting the current urban planning regulations. On the bottom right, the table from GIS software with data from cataloguing table linked to geometric data belonging to building polygon © 2021, Author.*

4. CONCLUSIONS

The study of aerial photographs of the city, georeferenced with GIS software, allows the association of Bologna expansion to geographic localization so that the areas built in the period 1946-1970 have been directly identified on the georeferenced municipal technical map. This sample is the starting point for the following development of this research. In fact, considering current urban prescriptions and regulatory framework, different dimensional and morphological parameters, and also thanks to the municipal database availability, has been identified an effective sequence for the selection of a sample of built-up areas referring to a specific period and type of future intervention (in this case, replacement), and this algorithm, tested in Bologna, might be potentially applied to many other urban contexts. The association using id codes for single buildings defined both in GIS software, according to a geographic coordinate system, and in the cataloguing table, enables the union of information collected from building permits consultation and the one included in the georeferenced municipal database, and also its representation and visualization on the urban territory. This is a great implementation to lots study; in fact, specific data about the buildings that are located on the sample of 173 areas are going to be available for the first time and used for assessing interventions on the existing heritage and defining a protocol supporting the decision-making process.

Finally, the critical analysis of these findings provides a general overview of one urban block that can be examined in a detailed way up to the single building, promoting the constant shifting from urban scale to the construction one and vice versa. The definition of a solid knowledge building heritage database, which can be accessible and searchable, is the starting point for developing preliminary assessments on city expansion in terms of density, services, allocations, and also problems connected to human activities increasing according to climate change and environmental context [12]. In this case, this database is going to be used for the formalization of an innovative circular model for the construction sector, a model that can be effectively applied and replicated at the national level.

5. REFERENCES

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