

Defining a Masonry Building Inventory for the City of Potenza

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Abstract. The seismic vulnerability assessment of masonry built heritage is an importance issue in Italy, due to the high seismic hazard of the territory and the huge amount of masonry buildings located in the exposed areas. The evaluation of the seismic performance of buildings can be useful to assess possible damages occurred after an earthquake, the direct costs which would result from it, the "pre" and "post" loss distribution in an urban area and the most vulnerable buildings. At urban scale, a building-specific assessment approach appears extremely difficult and time-consuming because of the large number of constructions. Therefore, being able to classify the built heritage in a limited number of territorial-specific structural typologies with similar characteristics would significantly simplify the vulnerability assessment.

This paper shows a typological and structural classification of existing masonry buildings of the historic center of Potenza (south of Italy) aimed at designing a virtual city consisting of different buildings categories. The main typological and structural features of the masonry constructions (MUR) have been identified through documentary analyses, Census data, site investigation and GIS-based analysis by considering the frequency of significant structural parameters. This represents the starting point of a comprehensive research study, carried out within the PON-AIM 2014–2020 project, aimed at the evaluation of the seismic resilience of the investigated area.

Keywords: Existing masonry buildings · Built heritage · Resilience

1 Introduction

The historic and recent earthquakes showed the problem of the seismic vulnerability of existing masonry constructions, most of which were generally designed without proper seismic resistance features. Therefore, the assessment of existing residential and historic masonry structures in highly seismic zones remains an important issue and a considerable challenge due to the nature and characteristics of these structures. The vulnerability assessment of these constructions has been investigated in the literature through different methods and focusing on different modeling issues [1–3].

Masonry structures are a much diffused type of construction which can be built rapidly, cheaply and often without any plan or particular technical competence.

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Masonry also represents the structural type of a large architectural heritage that needs to be preserved. Moreover, old unreinforced masonry buildings constitute the large majority of most urban aggregates in several seismic prone countries. The main characteristics of masonry buildings are high rigidity, low tensile and shear strength, low ductility and low capacity of bearing reverse loading. These are the main reasons for the frequent collapse of masonry buildings during earthquakes, often responsible for a considerable number of casualties.

A wide multiplicity of typologies can be found depending on available materials, climatic and functional requirements, technical knowledge and traditional practice specific to different countries [4]. Indeed, a wide variety of materials, both natural and artificial, and different structural typologies have been adopted in the past centuries for the construction of traditional masonry buildings. Therefore, the analysis of masonry constructions could be rather complex both for the variability of the materials used and for the lack of knowledge of some parameters (e.g. the construction systems adopted, the mechanical properties of the materials and the structural details, the changes occurred over time).

Detailed seismic vulnerability evaluation is a complex and expensive approach and can only be performed on a limited number of buildings. It is therefore very important to use simpler procedures that can help to rapidly evaluate the vulnerability profile of different types of buildings. In Europe and Italy, the built heritage of most of the cities is characterized by homogeneous areas, named compartment, featuring the same historical, urbanistic and constructive peculiarities. The identification of a limited number of territorial-specific structural typologies sensibly reduces the time-consuming with respect to a building-specific approach while maintaining a sufficient accuracy of the vulnerability assessment.

This paper presents the preliminary results of an ongoing research project, funded by the Operative National Program (PON) of Research and Innovation (2014–2010), finalized at assessing the seismic vulnerability of the city center of Potenza (southern Italy) and defining better resilience-building strategies in order to minimize losses and recovery time after an earthquake. This first step of the project consists of a critical survey of typological and structural characteristics of the investigated sample of buildings, such as building typology, construction period, adopted design standards, construction materials and structural configuration. In particular, an inventory of the main structural typologies of the residential masonry (MUR) constructions is presented herein. The characterization of the most frequent MUR typologies in the investigated area has been achieved through Census data, documentary analyses, site and virtual inspections (i.e. GIS-based analysis). In the first part, aggregated and disaggregated data are presented. In the second part, the structural typologies inventory is proposed.

2 Previous Approaches for Typologies Inventory Compiling

Building typologies identification is a fundamental preliminary step for any vulnerability or loss assessment process. Based on construction techniques, local and regional traditions, hazard history, climate conditions, and available materials, buildings can vary widely from one region to another. In order to manage these issues when

characterizing the building stock at a city wide scale, a common approach is the identification of a set of building types. The definition of building types depends on data availability and resources.

In the last decades, several international building classification schemes have been proposed. Most of them have been also integrated in comprehensive methodologies for the evaluation of the building vulnerability and implemented within international seismic codes [5, 6]. The building classification schemes are characterized by different levels of detail. The classification with respect to the construction material represents the most basic approach. The latter has been adopted within MSK–64 and later in the European Macroseismic Scale EMS [7, 8]. The second generation of building classifications introduced new and more specific parameters, such as age of construction/design code level, primary load bearing structure (only vertical or vertical and horizontal) and total height/number of stories [9]. Recently, very accurate building classification schemes have been proposed considering building shape in plan, structural irregularities, exterior wall materials and dimensions, that can affect the seismic performances [10].

The most common approach for the definition of a customized classification at regional scale consists in the employment of a Census database as primary source of information. The heterogeneous data provided by Census on buildings are then integrated using other territorial-specific sources of information (documental analysis, virtual and in situ inspections, etc.) [11, 12].

3 Description of the Case-Study

This work is carried out on the city of Potenza, located in Basilicata on a hill in the axial-active seismic belt (30 to 50 km wide) of southern Apennines (Fig. 1). The city was hit by several strong earthquakes (intensity higher than or equal to VIII MCS). In particular, the 1826 and 1857 events caused severe damage in the entire town imposing a massive demolition and reconstruction activity in the historical city center [13]. In the aftermath of the Irpinia and Basilicata earthquake (November 1980), a massive reconstruction plan, funded by the Italian Government (law 219/81), involved several existing buildings in the Potenza municipality.

An investigation on the built heritage of the city of Potenza is proposed in this paper. In particular, two main sample areas have been chosen for this study: the “old town center” and the “residential public housing neighborhood”. Those areas can be considered as homogeneous zones (compartments) featuring specific historical, urbanistic and constructive peculiarities. Moreover, such compartments include most of the historical built heritage of the city, developed in two main periods: 1850–1950 and 1945–1990, respectively. Due to the small amount and to the specific peculiarities of the public buildings, only the private residential building stocks will be considered herein.

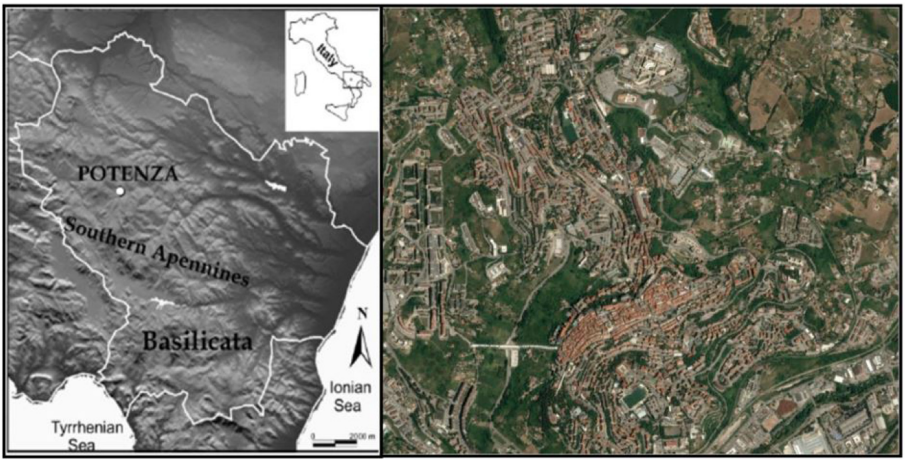

Fig. 1. Geographical location and urban area of Potenza (Basilicata Region, Southern Italy).

4 Building Typologies Definition

This work presents a specific building typologies inventory referred to the examined areas, issued by the combination of two different informative levels. Official national census databases provided by the Italian Institute of Statistics (ISTAT) were used as the primary source for the classification of the building stock, because they constitute the most reliable data source about buildings. Due to the privacy policy, such data are available only in the aggregated form: the number of masonry buildings in a certain census tract (CT) is known, but the number of masonry buildings realized in a specific period of construction or the number of masonry buildings featuring 2, 3 or more than 3 stories is unknown. For this reason, the primary Census data are successively integrated through secondary sources of information represented by extensive documental and virtual analysis and specific building surveys.

4.1 Census Data in Aggregated Form

Census data represent a fundamental source for a building typologies classification. In Italy, as in other countries, census data collection process provides a unique opportunity to build a complete small area mapping. The data provided by ISTAT are extremely populated (repeated every 10 years) and homogeneously distributed on the entire national territory.

Figure 2 shows the census areas of the city of Potenza and Table 1 reports the values of resident population and residential buildings in each Census Area. The old town center is included in area number 1 while the residential public housing neighborhood falls in census area number 3.

Figure 3 shows the selected census tracts of the old town center (in yellow and labeled as C1) and of the residential public housing neighborhood (in blue and labeled as C2).

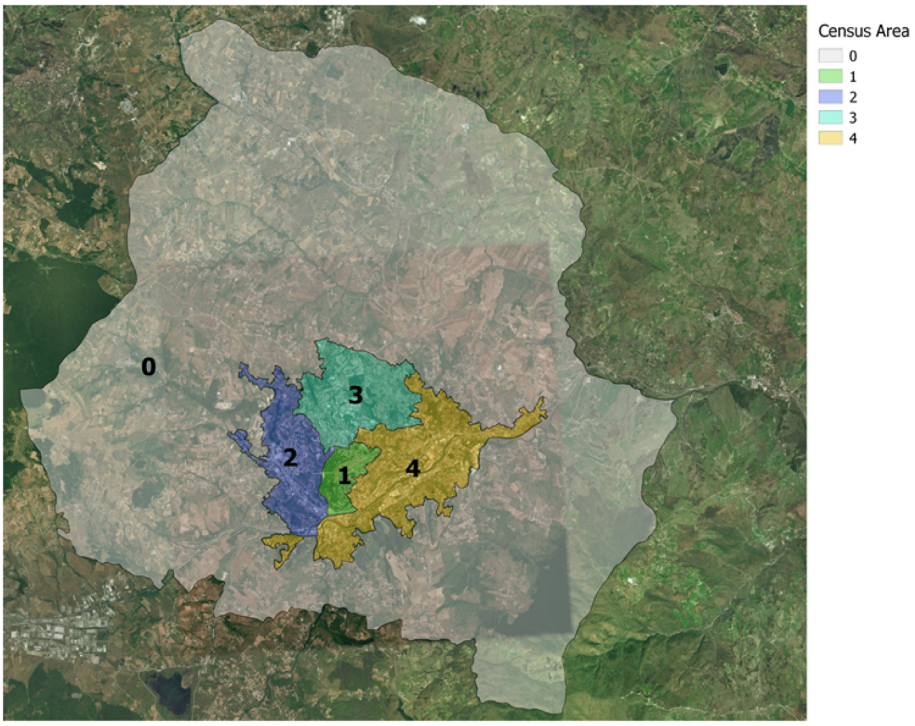

Fig. 2. Census areas of Potenza (ISTAT, 2011).

Table 1. Resident population and number of buildings in each Census Area (ISTAT, 2011).

Census area	Resident population	Residential buildings
0	10344	3132
1	12876	765
2	13343	915
3	14952	973
4	15262	2257

A list of available census variables useful for impact assessment referring to residential buildings is provided for each CT within the ISTAT "building database" referring to the 2001 census campaign [14]. Table 2, Table 3, Table 4 show the aggregated restitutions for buildings located in the two examined compartments.

Analyzing ISTAT data, the percentage of masonry buildings is prevalent in both compartments. This percentage is extremely high in the old town center (C1), being equal to approximately the 80%. Reinforced concrete buildings represent around 20% of the total, probably due to the demolition and reconstruction of old masonry buildings occurred between 1945 and 1970 [13, 15]. The percentage of masonry buildings is also

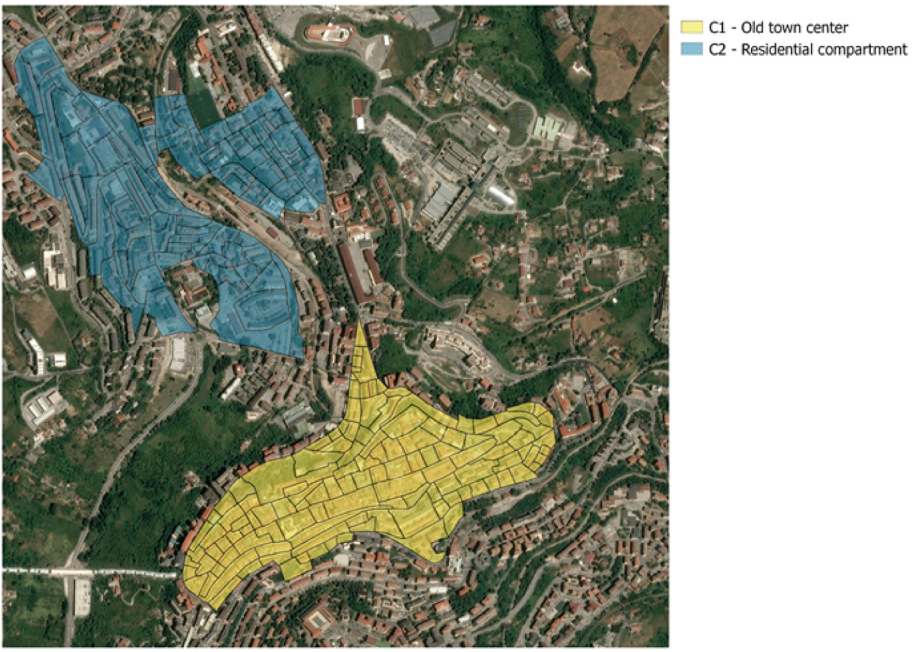

Fig. 3. Census tracts of the old town center (yellow) and residential (blue) compartments. (Color figure online)

Table 2. Percentage distribution of residential buildings in terms of construction materials for old town center (C1) and residential (C2) compartments.

	Masonry	RC	Other
C1	75.8%	23.8%	0.4%
C2	68.8%	31.2%	0.0%

Table 3. Percentage distribution of residential buildings in terms of age of construction for old town center (C1) and residential (C2) compartments.

	<1919	1919–1945	1946–1960	1961–1970	1971–1980	1981–1990	≥ 1991
C1	38.2%	21.0%	25.6%	4.4%	0.9%	9.3%	0.5%
C2	1.6%	0.8%	26.6%	36.7%	24.2%	10.1%	0.0%

high in the residential compartment (C2), where most of the buildings were built with load-bearing masonry structure during the period 1940–1960.

The percentage of buildings realized in the period 1971–1980 and after 1981 is not negligible. The whole historical center was subjected to significant seismic improvement interventions in the aftermath of the Irpinia and Basilicata earthquake (30th November 1980) that strongly hit the city center of Potenza.

Table 4. Percentage distribution of residential buildings in terms of number of stories for old town center (C1) and residential (C2) compartments (ISTAT, 2011).

	1	2	3	≥4
C1	8.4%	17.9%	22.4%	51.3%
C2	3.1%	10.2%	8.6%	78.1%

Finally, Table 4 shows that buildings featuring more than 4 stories are prevalent in both compartments (around 51% in the old town center and 78% in the residential compartment). Unfortunately, as mentioned before, based on the Census aggregated data no specific information is available to effectively separate the percentages of medium-rise and high rise buildings. On the other hand, the percentage of low-rise building (1–3 stories) can be directly estimated appearing not negligible, in particular in the old city center compartment (being equal to approximately 30%).

4.2 Secondary Sources of Information

Based on the Census data described in the previous section, two main variables emerged as significant classification parameters, namely the number of stories and the age of construction. Several studies showed that there is a close correlation between the period of construction and the structural behavior, almost independently of other construction characteristics, such as the state of conservation, which could improve or worsen the basic structural behavior [16].

The characterization of the masonry typologies in the investigated areas has been performed identifying the most significant parameters in addition to the number of stories and the construction period. The types of vertical structures (regular or irregular masonry), the horizontal structure (deformable or semi-rigid or rigid slab), the presence of mixed structures, the roof types, the presence of vaults, the presence of seismic structural intervention have been considered.

A comprehensive documental analysis has been carried out to identify the main characteristics of masonry buildings. In particular, a large database provided by the local organization of Social Housing (Azienda Territoriale per l'Edilizia Residenziale, ATER), strongly involved in the residential compartment construction and in the post-seismic reconstruction, has been analyzed. Moreover, a number of building-by-building surveys, providing detailed data for both dimensional and structural peculiarities for a single building in an investigated area, have been performed. Finally, other information has been gathered interviewing local technicians with deep knowledge of the construction characteristics.

Table 5 summarizes the main peculiarities of masonry constructions (MUR) derived by the described investigation with an example of building for each typology. Figure 4 shows the macro-classes in a GIS map.

The MUR1 typology concerns the first urban village built outside the historical center of the city in the 1920s. The buildings are made of square local stone or solid brick masonry with floors with hollow bricks and steel beams. Connections or devices for absorbing forces (e.g. steel roads) were not provided. The seismic behavior of this

Table 5. Preliminary macro-typologies inventory for the examined compartments.

PARAMETER	CHARACTERISTIC
MUR1 	Regular masonry (solid brick masonry) Semi-rigid slab (floor with hollow bricks and steel beams) Absence of vaults Absence of mixed structures Pitched roof with wood structure and planking Absence of seismic interventions
MUR2 	Regular masonry (cut stone with good bonding) Semi-rigid (vault floor with bricks and steel beams) Absence of vaults Absence of mixed structures Pitched roof with brick-concrete slab Localized interventions
MUR3 	Regular masonry (solid brick masonry) Rigid slab (floor with reinforced brick-concrete slab) Absence of vaults Absence of mixed structures Pitched roof with brick-concrete slab Absence of seismic interventions

MUR4 	Regular masonry (solid brick masonry) Rigid slab (floor with reinforced brick-concrete slab) Absence of vaults External masonry with internal RC frames Pitched roof with brick-concrete slab Absence of interventions
MUR5 	Regular masonry (solid brick masonry) Rigid slab (floor with reinforced brick-concrete slab) Absence of vaults Absence of mixed structures Pitched roof with brick-concrete slab Seismic improvement interventions

typology of construction is almost always ruled by the out of the plane mechanisms, because of the lack of effective connections between vertical and horizontal elements, giving rise to very high vulnerability to horizontal loads.

Between 1920 and 1940, the expansion of the city continued with the construction of the first buildings belonging to the National Institute for Housing of State Employees (INCIS) building program. The features of the MUR2 typology are external walls made of cut stone with good bonding and lime mortar, and vault floor with bricks and steel beams. Over the years, some of these buildings have been subjected to strengthening interventions, consisting mainly of widespread connections (insertion of metal bars or RC beams).

During the 1940s, the demographic increment produced the migration of the population to new urban areas located in the north of the city territory. In this context, an important public housing plan was pursued by the local organization of Social Housing (Azienda Territoriale per l'Edilizia Residenziale, ATER) creating two new residential neighborhoods. The third typology, named MUR3, groups masonry



Fig. 4. Macro-classes of masonry buildings located in the old town center and in the residential compartments.

constructions made by solid brick masonry and lime mortar with rigid slab (reinforced brick-concrete) and connections between vertical walls and the horizontal elements. This type of buildings is quite always characterized by a box-like seismic behavior, so being able to develop the more effective in plane mechanisms of the walls.

During the reconstruction after the Second World War, within a decade, in the 1950s, the urban landscape was remodeled with the presence of RC buildings, where the use of load-bearing masonry progressively gave way to the use of lightweight infills. An evolution, characterized by a higher heterogeneity in the building solutions was noticed: from structures in masonry to mixed structures where horizontal and vertical RC elements are in contact with masonry. The MUR4 typology is characterized by external masonry walls and internal RC beam-column systems with reinforced brick-concrete floor.

The 1980 Irpinia-Basilicata earthquake devastated a wide area of the Southern Apennines, especially Campania and Basilicata where about thirty towns were completely destroyed. In Potenza 10000 people became homeless and public buildings suffered heavy damage. For this reason, the old town was subjected to a massive repair and reconstruction plan. The MUR5 typology characterizes the reconstructed buildings of the historical center. The "ancient" masonry, characterized by disordered rubble stone with friable mortar and textures made of irregular and sub-horizontal courses, was replaced by regular masonry of solid brick stones. The deformable timber floors without steel chains and RC tie-beams were replaced by rigid floors with reinforced brick-concrete slab. Widespread seismic improvement interventions (application of diffused tie-roads, filling the voids and/or cracks inside the wall by injecting of new mortar, substitution of damaged elements along cracking lines with new ones, etc.) were performed. It is worth nothing that the historical center of Potenza, like most of the historical centers in Italy, consists of several masonry aggregates, interconnected, multilevel, masonry cells, which share common structural elements (walls, roofs, staircases, etc.) This affects not only the individual behavior of each construction but also their combined behavior. For this reason, besides analyzing the seismic response of each individual structural unit, its role within the aggregate will be analyzed with the aim to highlight the different behavior of the unit when considered as isolated or part of an aggregate.

The preliminary inventory proposed in Table 5 has been further refined considering other specific building characteristics that effectively affect the seismic behavior. In addition to the aforementioned number of stories, significant attributes emerged from the described documental and in situ investigation. Among those, irregularities in plan and the presence of connections between slabs and walls cannot be ignored for a comprehensive evaluation of the building typologies. With regard to the number of stories, the analyzed data showed that masonry constructions in the investigated areas can be grouped into three classes: low-rise buildings "Lr" (1–2 stories), medium-rise buildings "Mr" (3–4 stories) and high-rise buildings "Hr" (5–6 stories). With reference to the second parameter, two major classes of buildings have been identified: regular "Reg." and irregular "Irreg." building shape in plan. Finally, the presence of slab-wall connections has been considered. As described above, after the 1940s there was the transition from deformable or semi-rigid floors to rigid reinforced concrete floors. In fact, the analyzed documents showed that the masonry buildings built in the 1950s and 1960s, representative of the residential compartment, have rigid floors with RC beam. So, other two classes have been considered taking into account the presence or not of slab-wall connections, named "C" and "Nc" respectively.

The final building inventory, obtained adopting the classification approach described in the previous sections, is proposed in Table 6.

Table 6. Building typologies inventory for the examined compartments.

MACRO-CLASS	Number of stories			Shape in plan		Slab-wall connections		ID
	Lr	Mr	Hr	Reg.	Irreg.	C	Nc	
MUR1	x			x		x		MUR1, Lr, Reg, C
	x			x			x	MUR1, Lr, Reg, Nc
	x				x	x		MUR1, Lr, Irreg, C
	x				x		x	MUR1, Lr, Irreg, Nc
		x		x		x		MUR1, Mr, Reg, C
		x		x			x	MUR1, Mr, Reg, Nc
		x			x	x		MUR1, Mr, Irreg, C
		x			x		x	MUR1, Mr, Irreg, Nc
			x	x		x		MUR1, Hr, Reg, C
			x	x			x	MUR1, Hr, Reg, Nc
			x		x	x		MUR1, Hr, Irreg, C
			x		x		x	MUR1, Hr, Irreg, Nc
MUR2	x			x		x		MUR2, Lr, Reg, C
	x			x			x	MUR2, Lr, Reg, Nc
	x				x	x		MUR2, Lr, Irreg, C
	x				x		x	MUR2, Lr, Irreg, Nc
		x		x		x		MUR2, Mr, Reg, C
		x		x			x	MUR2, Mr, Reg, Nc
		x			x	x		MUR2, Mr, Irreg, C
		x			x		x	MUR2, Mr, Irreg, Nc
			x	x		x		MUR2, Hr, Reg, C
			x	x			x	MUR2, Hr, Reg, Nc
			x		x	x		MUR2, Hr, Irreg, C
			x		x		x	MUR2, Hr, Irreg, Nc
MUR3	x			x		x		MUR3, Lr, Reg, C
	x			x			x	MUR3, Lr, Reg, Nc
	x				x	x		MUR3, Lr, Irreg, C
	x				x		x	MUR3, Lr, Irreg, Nc
		x		x		x		MUR3, Mr, Reg, C
		x		x			x	MUR3, Mr, Reg, Nc
		x			x	x		MUR3, Mr, Irreg, C
		x			x		x	MUR3, Mr, Irreg, Nc
			x	x		x		MUR3, Hr, Reg, C
			x	x			x	MUR3, Hr, Reg, Nc
			x		x	x		MUR3, Hr, Irreg, C
			x		x		x	MUR3, Hr, Irreg, Nc
MUR4	x			x		x		MUR4, Lr, Reg, C
	x			x			x	MUR4, Lr, Reg, Nc
	x				x	x		MUR4, Lr, Irreg, C
	x				x		x	MUR4, Lr, Irreg, Nc
		x		x		x		MUR4, Mr, Reg, C
		x		x			x	MUR4, Mr, Reg, Nc
		x			x	x		MUR4, Mr, Irreg, C
		x			x		x	MUR4, Mr, Irreg, Nc
			x	x		x		MUR4, Hr, Reg, C
			x	x			x	MUR4, Hr, Reg, Nc
			x		x	x		MUR4, Hr, Irreg, C
			x		x		x	MUR4, Hr, Irreg, Nc

(*continued*)

Table 6. (*continued*)

MACRO-CLASS	Number of stories			Shape in plan		Slab-wall connections		ID
	Lr	Mr	Hr	Reg.	Irreg.	C	Nc	
MUR5	x			x		x		MUR5, Lr, Reg, C
	x			x			x	MUR5, Lr, Reg, Nc
	x				x	x		MUR5, Lr, Irreg, C
	x				x		x	MUR5, Lr, Irreg, Nc
		x		x		x		MUR5, Mr, Reg, C
		x		x			x	MUR5, Mr, Reg, Nc
		x			x	x		MUR5, Mr, Irreg, C
		x			x		x	MUR5, Mr, Irreg, Nc
			x	x		x		MUR5, Hr, Reg, C
			x	x			x	MUR5, Hr, Reg, Nc
			x		x	x		MUR5, Hr, Irreg, C
			x		x		x	MUR5, Hr, Irreg, Nc

5 Conclusions

In this paper, a simplified approach aimed at assembling a building typologies inventory is presented and applied for the urban residential area of Potenza (southern Italy). In particular, the proposed approach combines the primary informative level represented by Census-based database with a second complementary informative level based on specific documental/virtual analysis, building-by-building surveys and expert judgment. A preliminary inventory composed by five macro-typologies has been defined. Such preliminary inventory has been then refined considering specific building structural peculiarities affecting the seismic behavior. Sixty typologies have been finally identified. It is worth noting that the structural element dimensions (derived from the described investigation), the building position in a block aggregate (isolated, corner, end or central) and the percentage and arrangement of openings in walls will be opportunely taken into account at a later stage of the PON AIM research project and, in particular, during the numerical modeling of the selected archetype buildings.

The research activity described in this paper represents the primary step of a comprehensive study for the evaluation of the seismic resilience of the investigated area. A complementary study regarding the reinforced concrete residential buildings located in the examined compartments has been carried out in parallel by the same Authors of this paper.

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