

# Reconstruction process of damaged residential buildings outside historical centres after the L’Aquila earthquake: part I—“light damage” reconstruction

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**Abstract** Assessment of the seismic damage and usability of the building stock started a few days after the L’Aquila earthquake in order to evaluate the safety conditions of the buildings concerned. Several ordinances of the Prime Minister were issued to regulate the reconstruction process. In particular, based also on damage level, the procedures for repair, strengthening or demolition/reconstruction of residential buildings were established with the definition of relevant state funding. For each damaged building, practitioners engaged by property owners designed repair and strengthening interventions and then computed the corresponding costs. These projects were the technical basis for funding applications that owners submitted to the government. Technical and financial information collected during the approval procedure of such applications allowed compilation of a database regarding 5775 residential buildings damaged by the L’Aquila earthquake. The present study examines the restoration policy and the procedures regulating the reconstruction process of residential property outside city centres. In particular, the data related to the first phase of the reconstruction process (the so-called “light damage” reconstruction) to recover the usability of slightly damaged buildings are illustrated. The discussion focuses on the time-to-approval of funding applications and on the public contributions granted for repair and local strengthening works.

**Keywords** Earthquake damage · Reconstruction · Public grant · Repair and strengthening · Costs · RC and masonry buildings

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## 1 Introduction

Italy has experienced more than 60 destructive earthquakes over the past two centuries which have caused more than 149,000 deaths. The Messina and Reggio Calabria earthquake of 1908 ( $M_w = 7.1$ , 85,926 deaths) and the Abruzzo earthquake of 1915 ( $M_w = 7.0$ , approximately 32,610 deaths) alone caused more than 115,000 deaths. Over the past 45 years, starting from the devastating earthquake of Belice in 1968, the death toll has been about 4500, corresponding to approximately 100 deaths/year. In addition to the large toll, these earthquakes have dramatically impacted on the country's economy in terms of direct costs (emergency management and reconstruction) and indirect costs (significant reduction in GDP due to the fall in agricultural and industrial production and related tax revenue, and costs of social and psychological support to the affected population, etc.). The direct costs related to the emergency management and reconstruction process in Italy between 1968 and 1998 were estimated to exceed €100 billion (by the 2005 euro equivalent); mainly related to the earthquakes of Belice in 1968, Friuli in 1976, Irpinia in 1980, and Umbria-Marche in 1997 (Severino and Di Pasquale 2002). These costs are considerably increased if due allowances are made for the seismic events of the last 15 years, including events in Molise (2002), L'Aquila (2009) and Emilia (2012). Indeed, the L'Aquila earthquake left nearly 70,000 homeless and the Emilia earthquake strongly impacted on productivity of primary importance for the local and national economy.

Management of both the post-earthquake emergency phase and the recovery phase is strongly dependent on the local context and on the time when the seismic event occurs. The models of post-earthquake emergency management and reconstruction used since the 1968 Belice earthquake have all been based on ensuring fair public coverage of the costs required to repair the earthquake damage in question. However, the technical and administrative procedures for the implementation of the reconstruction have been refined over time to allow for the experience of previous earthquakes and for the improvement of technical and scientific knowledge. In this respect, analysis of the recent Italian earthquakes in Irpinia, Umbria-Marche and L'Aquila has identified significant aspects of the reconstruction models and how they have changed over time according both to the territorial context and advances in knowledge, especially of a scientific nature.

The set of regulations issued after the Irpinia 1980 earthquake to provide financial support for the repair/reconstruction of buildings showed a strong political willingness to demolish severely damaged masonry buildings and replace them with reinforced concrete (RC) buildings. The maximum public grant for repair/reconstruction of damaged buildings was mainly calibrated on the basis of a single parameter: the maximum cost for reconstruction,  $CR = CI \times S$  [with  $CI$  being the intervention unit cost of about €530/m<sup>2</sup> (expressed as € as at year 2000)] and  $S$  the gross surface area of each dwelling (Legislative Decree D.Lgs no. 76 1990; Law L. no. 32 1992).

After the Umbria-Marche 1997 earthquake, the distinction between “light damage” reconstruction and “heavy damage” reconstruction was introduced. The distinction was made in order to differentiate the phases of the reconstruction process as a function of the observed damage on the vertical structures as issued in the specific post-earthquake laws. The aim was to account for the fact that different damage levels correspond to the different times and costs of recovery. The definition of two reconstruction phases was also made to enable rapid re-occupancy of slightly damaged buildings, thus significantly reducing public costs incurred in housing the homeless. The public grant to repair the damaged buildings concerned was mainly calibrated on the basis of two parameters: the damage (amount and

type) and the vulnerability of the original building (i.e. the building in its configuration before the earthquake damage). These parameters were computed in a simplified way according to suitable criteria issued by Law Decree no. 180 of January 30 1998 and DGR no. 2153/1998. Based on these two parameters, it was possible to define five public grant thresholds, SxLi, to cover costs related to structural repair and strengthening (or building replacement) and finishing works:  $L1 = 227 + 114 = €341/m^2$ ;  $L2 = 283 + 141 = €424/m^2$ ;  $L3 = 350 + 175 = €525/m^2$ ;  $L4 = 416 + 208 = €624/m^2$ ;  $L5 = 462 + 231 = €693/m^2$  (expressed as € at year 2001).

These costs could increase by up to a maximum of 40 %, according to several criteria (e.g. seismic hazard of the area, green architecture, etc.). They did not include VAT while they included charges for the design and technical assistance of practitioners.

The distinction of two reconstruction phases, “light damage” and “heavy damage” reconstruction, was also adopted in the L’Aquila 2009 post-earthquake reconstruction process. However, in this case the definition of the building damage level was based on the usability assessment.

The repair costs were fully covered by the public grant, while different economic thresholds were defined for local or global strengthening works. A procedure was also provided to compute the maximum allowable grant in the case of buildings requiring demolition and reconstruction (OPCM no. 3779 2009; Annex to OPCM no. 3779 2009; OPCM no. 3790 2009; Annex to OPCM no. 3790 2009; OPCM no. 3881 2010). Furthermore, the reconstruction process clearly distinguished the contribution allocated for Condominium Units (termed CU), Common Areas (CA) and Independent Dwellings (ID). The funding application for CU involved the repair works only; the funding applications of CA and ID involved both repair and local or global strengthening works.

Details about the procedures issued for the regulation of the post-L’Aquila earthquake reconstruction process outside the historical centre of L’Aquila and surrounding municipalities (i.e. buildings located outside the historical walls) are reported in Sect. 2. Section 3 presents the data related to the usability rating of the damaged buildings and their characteristics while Sect. 4 focuses on the first phase of the reconstruction process (so-called “light damage” reconstruction) aimed at recovering the usability of slightly damaged buildings. In particular, the time-to-approval of applications, repair and local strengthening interventions and their unit costs are presented and discussed. The second phase of the reconstruction process (so-called “heavy damage” reconstruction) is discussed in a companion paper (Di Ludovico et al. 2016, under review).

## 2 Reconstruction procedures for residential buildings

The reconstruction process of residential buildings outside the historical centres damaged by the L’Aquila earthquake started once specific ordinances had been issued. In particular, it has been mainly regulated by the following Ordinances of the President of the Council of Ministers (OPCM): OPCM no. 3779 (2009), OPCM no. 3790 (2009), and OPCM no. 3881 (2010). They established that the financial support of the Italian government to the reconstruction was given and managed by private owners; the financial support was based on the building usability rate, as determined by in situ inspections of team of experts in the immediate aftermath. Buildings are interpreted as structural units (e.g. ID or CA and relevant CU that is a condominium consisting of common areas and residential units

belonging to the same building) of ordinary constructional typology. Note that in residential buildings commercial private units are also included.

Assessment of building usability started in the immediate aftermath of the L'Aquila earthquake under the coordination of the Italian Civil Protection Department (Dolce et al. 2009). The AeDES form, a first level survey form for post-earthquake damage and usability assessment, was adopted as a rapid tool to evaluate the conditions of the buildings (Baggio et al. 2007). The purpose of this form is to assess whether the building has been damaged by the earthquake and if it can still be used, in relation to its residual seismic safety. The usability and damage assessment was carried out by teams of two or three expert surveyors. In the AeDES form, each building was classified into categories:

- A. Usable building (slightly damaged, can keep on performing its allocated functions);
- B. Usable building, but only after short-term countermeasures (a building with limited or no structural damage but with severe non-structural damage);
- C. Partially usable building (a building with limited or no structural damage but with severe non-structural damage located in part of the building);
- D. Building to be re-inspected (due to atypical damage a specific, but still visual, investigation is required);
- E. Unusable building (high structural or non-structural risk, high external or geotechnical risk);
- F. Unusable building from external risk alone.

The financial strategy of the Italian government was to fully cover the repair costs of CA and primary residences (CU or ID); for secondary residences (CU or ID) repairs were covered up to 80 % of the repair cost up to a maximum of €80,000. In addition, further contributions were given for strengthening interventions on CA or ID. An upper bound, inclusive of VAT and charges for the design and technical assistance of practitioners, was based on the usability rate of each building:

– *B or C usability rating*

- €150/m<sup>2</sup> (of the overall building gross surface area) for local strengthening of critical structural and non-structural members (OPCM no. 3779 2009);

– *E usability rating*

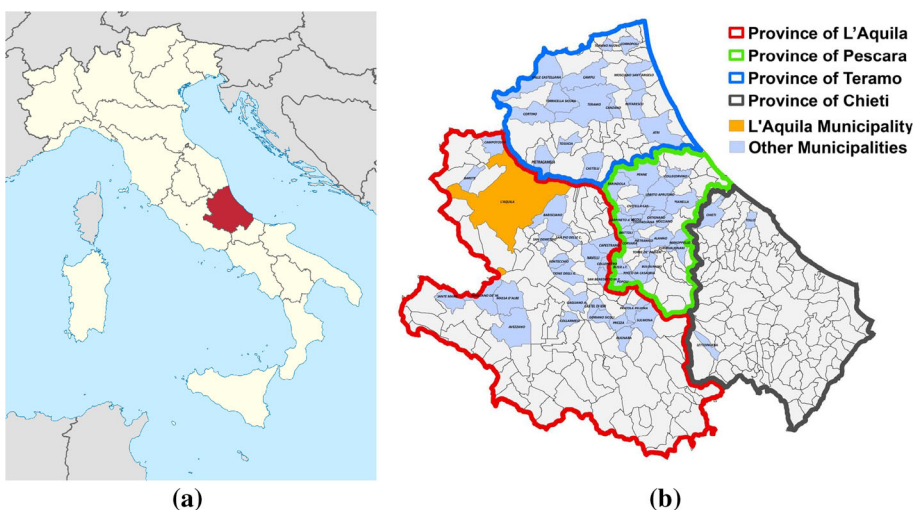
- €250/m<sup>2</sup> for the local strengthening of buildings with an E usability rating but with high non-structural risk and slight structural damage, termed E–B funding class in the reconstruction approval process (OPCM no. 3790 2009);
- €400–600/m<sup>2</sup> for the seismic retrofit of severely damaged buildings; this contribution covered strengthening at least up to 60 % (and no more than 80 %) of the level required for new buildings designed according to Italian current seismic code (DM 14.01.2008 2008; Circular no. 617 02.02.2009 2009). For retrofitting to more than 80 % compliance with the current seismic code, the extra costs for retrofitting above 80 % should be at the owner's expense (OPCM no. 3790 2009);
- for buildings with usability rate E, public grants for demolition and reconstruction were also allowed if such interventions were deemed economically viable (economic convenience criterion); the grant is the lower of that for repair and strengthening to a minimum safety level of 60 % and that for demolition and reconstruction. In the case of demolition and reconstruction (termed Edem funding class in the reconstruction

approval process) OPCM no. 3790 (2009) required the designer to demonstrate that the repair and strengthening costs (to meet at least 60 % of the current seismic code action requirements) exceed the demolition and reconstruction costs computed according to OPCM no. 3881 (2010). Furthermore, in specific cases (i.e. totally collapsed buildings, masonry structures partially collapsed—more than 25 % in volume, more than 50 % of storey columns with a residual drift greater than 1.5 % for RC structures, average compressive cylindrical strength lower than 8 MPa for RC structures), public grants for the demolition and reconstruction were available without economic assessment. The public grant was computed according to OPCM no. 3881 (2010).

For each building, repairs, local or global strengthening interventions, or demolition and reconstruction, as well as costs, were respectively designed and computed by practitioners engaged by owners. Documentation was required to illustrate the damage and the design of repair and strengthening interventions, to assess the building's original and post-intervention seismic capacity (for buildings with usability rate E) and to quantify the government financial support required.

A team was set up to oversee these projects and to deal with the numerous applications for funding (OPCM no. 3803 2009; OPCM no. 3827 2009). This team, called “*Filiera*” (i.e. an Italian word to indicate a supply chain mechanism) comprised three groups, each of which had separate responsibilities:

- Fintecna, a company totally owned by the State through the Italian Ministry of Economics and Finance, to evaluate the formal suitability and comprehensiveness of the application and documentation (administrative check);
- ReLUIS, an interuniversity consortium with the purpose of coordinating the university laboratory activity of seismic engineering, to evaluate the consistency between repair intervention and damage and the compliance between designed local (or global) strengthening interventions and current seismic code provisions and ordinances issued after the L'Aquila earthquake;



**Fig. 1** Italy map and Abruzzi Region (a), municipalities involved in the reconstruction process (b)

- Cineas, a university consortium for Insurance Engineering, to evaluate the appropriacy of the application for a financial rebate, also based on the technical assessment made by ReLUIS.

The Filiera activity began in August 2009 and ended in March 2013. The applications for funding were related to the L’Aquila municipality and other municipalities, see Fig. 1; in particular, applications from 63 municipalities were submitted to the Filiera: 24

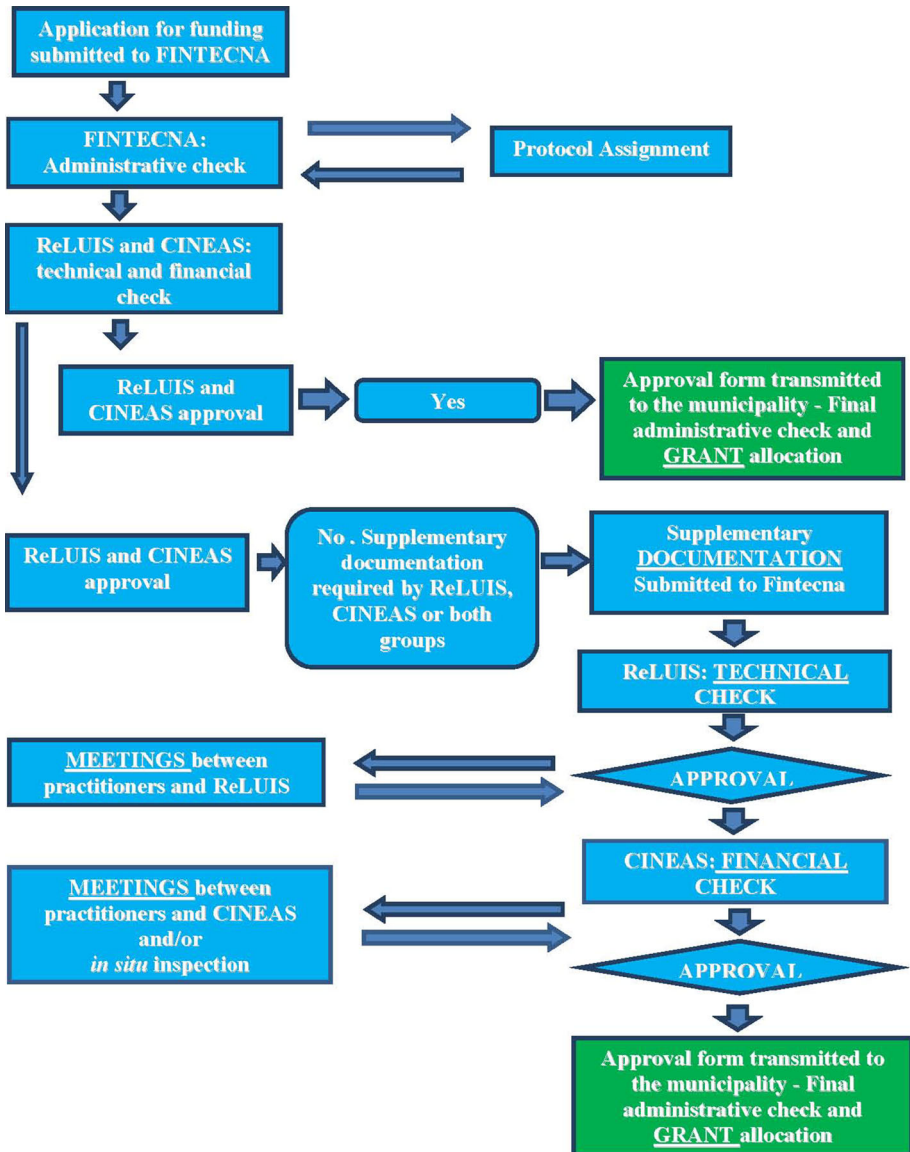


Fig. 2 Application for funding approval process

municipalities in the Province of L’Aquila; 22 municipalities in the Province of Pescara; 14 municipalities in the Province of Teramo; 3 municipalities in the Province of Chieti.

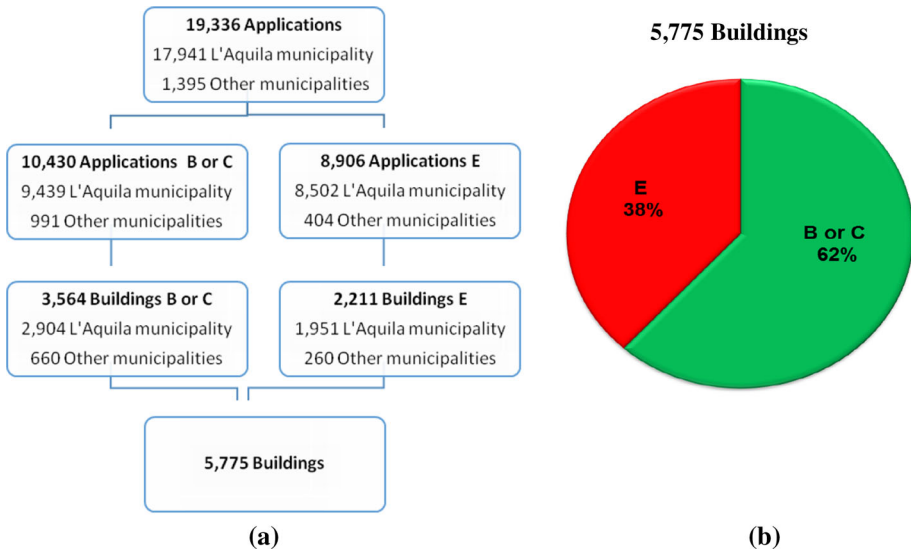
The approval process of applications for funding is illustrated in Fig. 2. Once the administrative section of the application had been checked and approved by Fintecna, the technical documentation was transferred to ReLUIS and Cineas for an initial check phase. In particular, the consistency between the reported damage and the proposed repair and strengthening interventions, as well as their compliance with current seismic code provisions (D.M. 14.01.2008 2008; Circular no. 617 02.02.2009 2009; OPCM no. 3779 and relevant Annex 2009; Annex to OPCM no. 3779 2009) was checked by ReLUIS; the costs associated to the application were checked by Cineas. If the application was approved by both consortia, the Filiera transmitted the approval form for transferring the financial contribution to the public offices of the municipality concerned. In some cases, the application was incomplete and supplementary documentation was necessary to clarify technical aspects or those related to cost computation; in these cases, sometimes more than one iteration was necessary to re-check the application. To facilitate the final approval and to speed up the process, meetings between practitioners and ReLUIS and/or Cineas representatives were possible at this stage to discuss the required clarifications.

The Filiera activity involved residential buildings outside the historical centres. In this period, 19,716 applications for funding were submitted and 19,336 were approved (380 applications failed to comply with provisions issued under post-earthquake ordinances (OPCM no. 3779 2009; OPCM no. 3790 2009). In particular, 17,941 applications for funding were related to the L’Aquila municipality and 1395 applications to other municipalities, see Table 1 and Fig. 3. Of the applications approved, 10,430 were submitted for buildings with usability rating B or C and 8906 for those with usability rating E (see Fig. 3).

According to the Ordinances (OPCM no. 3779 2009; OPCM no. 3790 2009), an application was necessary for each CU, CA or ID. Thus the 19,336 projects and relevant applications for funding submitted to the *Filiera* corresponded to 5775 buildings (Table 1; Fig. 3). By the term “building” we mean a structural unit consisting of ID or CA and relevant CU. The usability rating of the 5775 buildings was: 3546 (i.e. 62 %) buildings had a usability rating of B or C and 2211 (i.e. 38 %) buildings had an E rating.

**Table 1** No. of applications in L’Aquila municipality and other municipalities, usability rating and No. of buildings

| Municipality         | No. of applications | Usability rating | Unit | No. of buildings |
|----------------------|---------------------|------------------|------|------------------|
| L’Aquila             | 1534                | B or C           | ID   | 2904             |
|                      | 1370                |                  | CA   |                  |
|                      | 6535                |                  | CU   |                  |
| Other municipalities | 480                 | B or C           | ID   | 660              |
|                      | 180                 |                  | CA   |                  |
|                      | 331                 |                  | CU   |                  |
| L’Aquila             | 560                 | E                | ID   | 1951             |
|                      | 1391                |                  | CA   |                  |
|                      | 6551                |                  | CU   |                  |
| Other municipalities | 168                 | E                | ID   | 260              |
|                      | 92                  |                  | CA   |                  |
|                      | 144                 |                  | CU   |                  |



**Fig. 3** Application for funding approved by the Filiera

Finally, the applications for funding concerned 4855 (i.e. 84 %) buildings in the municipality of L'Aquila and 920 (i.e. 16 %) in other municipalities (Table 1; Fig. 3).

### 3 The damaged building stock

The technical approval of applications for funding related to damaged buildings allowed the Filiera to collect a database containing information on 5775 residential buildings outside the historical centres of the L'Aquila and other municipalities. For each building the following data were collected:

1. Address and usability rating (B or C, E);
2. Structural type (RC, masonry, steel, etc.);
3. Number of storeys;
4. Gross surface area;
5. Age of construction;
6. Number of residential units (CU and ID) and buildings (ID or CA and relevant CU);
7. Time-to-approval of application for funding;
8. Repair costs of residential units;
9. Costs for structural repair and local strengthening interventions (B or C, or E-B funding class), or seismic capacity enhancement interventions (E funding class, seismic capacity increase up to a minimum level of 60 % and a maximum level of 80 % with respect to current design seismic demand). These costs were related to CA and ID applications;
10. Main strengthening solutions to increase seismic capacity;
11. Demolition and reconstruction costs ( $E_{dem}$  funding class).



Out of 5775 buildings, 95 % of the database concerns RC or masonry buildings (49 % RC and 46 % masonry, respectively), while the remaining 5 % involves buildings with a mixed structural type (i.e. comprising RC and masonry structural members), steel structure or other types, see Table 2. The table shows that RC is the most common structural type in buildings with usability rating B or C; by contrast, masonry is the most common structural type in the case of buildings with usability rating E.

The buildings damaged by the earthquake have been also classified according to the number of storeys and construction age for each usability rating. The construction age is classified according to seven periods (i.e. before 1919, between 1919 and 1945, 1946–1961, 1962–1971, 1972–1981, 1982–1991, after 1991) as commonly adopted in the census data collections (and in the AeDES form). From the data collected it was possible to determine both parameters (construction age and number of storeys) on 4381 buildings made by RC (2498 buildings) or masonry structure (1883 buildings). In Fig. 4a the number of RC and masonry buildings, as well as the cumulative percentage of buildings (red dashed line), is reported as a function of the period of construction; the same quantities are also reported as a function of storeys in Fig. 4b. The graphs show that the number of masonry buildings is almost the same for periods before 1961 (on average about 400 buildings per period), while it strongly decreases for periods after 1961. Most of the masonry buildings have 2 or 3 storeys (795 and 705 buildings, respectively, corresponding to 80 % of the masonry building dataset). By contrast, the number of RC buildings starts to be significant in periods after 1961, with peaks of 663 and 723 buildings in 1972–1981 and 1982–1991 (1386 buildings corresponding to 55 % of the RC building dataset). Furthermore, most of the RC buildings have 3 or 4 storeys.

The percentage ratio of buildings B or C, and E versus the set of buildings belonging to each construction age or storey class is reported in Fig. 5a, b, for RC buildings and in Fig. 5c, d, for masonry buildings.

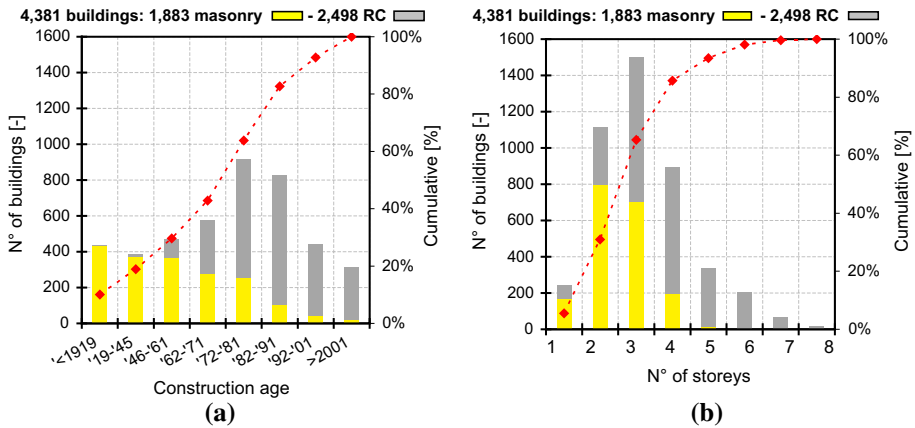
Since the set of RC buildings belonging to classes before 1946 or with more than six storeys is very small (see Fig. 4a, b) they are not reported in Fig. 5a, b. Similarly, masonry buildings built after 1991 or with more than four storeys are not reported in Fig. 5c, d.

As for RC buildings, Fig. 5a shows that the percentage of buildings with usability rating E has a decreasing trend for more recent construction ages. The share of B or C buildings exceeds 50 % (i.e. it exceeds E buildings for a given construction age period) starting from the period 1972–1981.

The higher the number of storeys of RC buildings, the higher the proportion of buildings with usability rating E (see Fig. 5b). However, with the exception of six-storey buildings (55 % of the buildings belonging to this class are rated E) the proportion of E buildings is always lower than that of B or C buildings.

**Table 2** No. of buildings in each usability rating class and structural types

| Building stock | Usability rating | No. of buildings | Structural type | No. of buildings |
|----------------|------------------|------------------|-----------------|------------------|
| 5775           | B or C           | 3564             | RC              | 1738             |
|                |                  |                  | Masonry         | 1580             |
|                |                  |                  | Other types     | 246              |
|                | E                | 2211             | RC              | 1059             |
|                |                  |                  | Masonry         | 1093             |
|                |                  |                  | Other types     | 59               |



**Fig. 4** Construction age and number of storeys of RC and masonry buildings

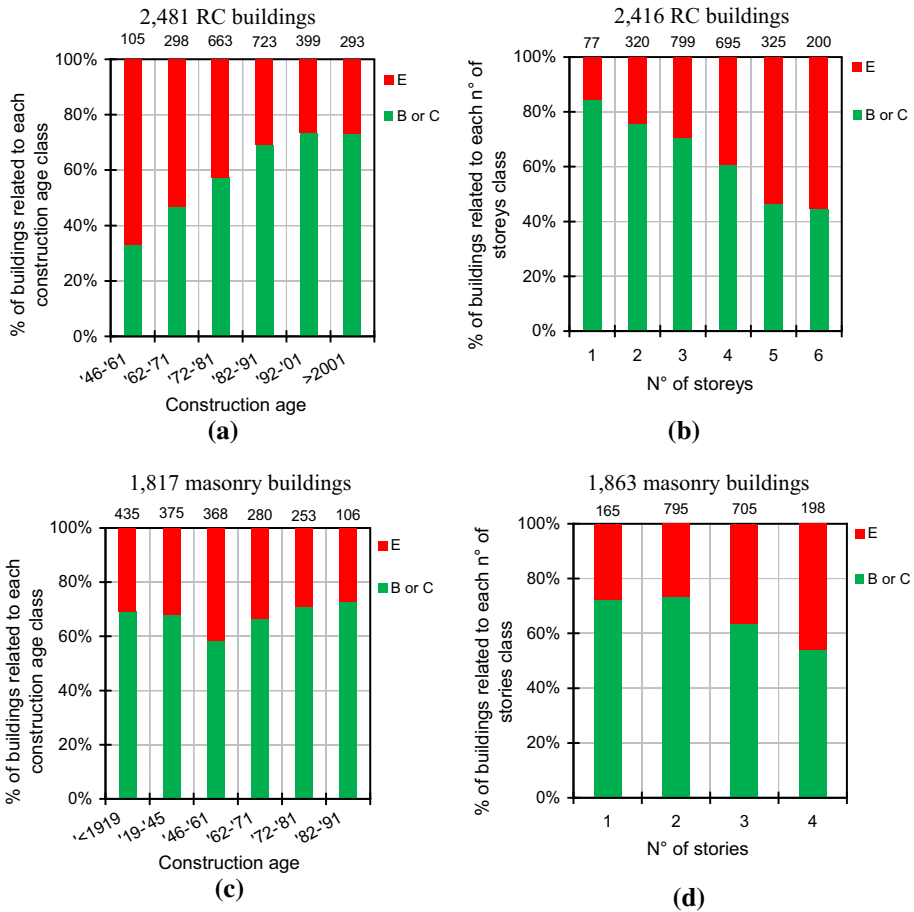
The construction age affected the usability rating of masonry buildings less than for RC buildings; the share of B or C buildings is almost constant for each period of construction and roughly twice that of E buildings (i.e. about 66 % versus 33 %). For masonry buildings with 1 or 2 storeys the proportion of buildings with usability rating B or C is approximately 70 % while it decreases for buildings with 3 or 4 storeys to a minimum of about 50 %.

Although the dataset refers only to a fraction of the damaged buildings and involves buildings located in a vast area affected by different earthquake intensity, the graphs indicate a direct link between the usability rating and construction age for RC buildings and between the usability rating and the number of storeys for masonry buildings. The influence of construction age on the structural damage of RC buildings is plausibly not only due to their poor maintenance but also takes into account increasingly stringent seismic provisions and construction procedures. By contrast, in the case of masonry buildings the construction age is unlikely to have had such a clear-cut effect on the amount of structural damage because the most significant seismic code amendments were enacted when masonry had gradually started to be replaced by reinforced concrete. In the case of masonry buildings the number of storeys was more significant than the construction age.

In the next section the data collected for buildings with usability rating B or C are presented and discussed in order to illustrate the various aspects of the first stage of the reconstruction process (so-called “light damage” reconstruction), including: time-to-approval of applications; funding allocated for reconstruction; local strengthening interventions adopted for RC and masonry buildings; repair costs of residential units as well as repair and strengthening costs of buildings; influence of building characteristics on repair and strengthening costs.

#### 4 “Light damage” reconstruction

In order to promote a rapid reconstruction process, the applications related to buildings with slight structural damage (i.e. B or C usability rating) were first submitted for funding approval. According to OPCM no. 3779 (2009), the technical documentation provided by practitioners to the *Filiera* consisted of: a report with pictures showing the damage caused



**Fig. 5** Usability rating of RC buildings measured against construction age (a) or number of storeys (b), usability rating of masonry buildings measured against construction age (c) or number of storeys (d)

by the earthquake; the design and drawings of the repair and, in several cases, of the strengthening interventions; the detailed computation of the funding application.

To support the engineers involved in the L’Aquila reconstruction process, DPC and ReLUIIS published the “Guidelines for Repair and Local Strengthening of Structural and Non-Structural Members” in August 2009 to provide detailed descriptions of repair methods and strengthening interventions [DPC (Civil Protection Department) and ReLUIIS (Laboratories University Network of Seismic Engineering) 2011]. The guidelines first outline the typical damage observed on both structural and non-structural members of RC and masonry buildings. Then local strengthening interventions, both for structural and non-structural members, are described by illustrating the installation and calculation procedures. In particular, several types of local strengthening interventions on structural elements are presented: local retrofit of RC beam-column joints as well as strengthening of beams, columns and slabs by means of FRP systems (Di Ludovico et al. 2008a, b; Del Vecchio et al. 2014, 2015; Frascadore et al. 2015); steel jacketing or prestressed steel

ribbons (Active Confinement of Manufactured materials, CAM) on RC members or beam-column joints; strengthening interventions on masonry structures by means of traditional and innovative techniques; local strengthening of timber elements.

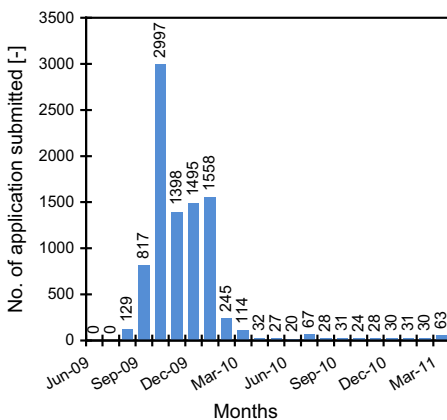
#### 4.1 Application for funding: submissions and approvals

The submission and the time-to-approval of applications related to buildings with usability rating B or C in the L'Aquila municipality (outside the historical centre) are herein presented and discussed.

OPCM no. 3779 (2009) and the relevant Annex (2009) were enacted in June 2009 and the number of applications/month submitted to Fintecna from June 2009 is shown in Fig. 6. Applications were submitted as from August 2009. In the following 6 months to January 2010 an average of about 1400 applications were submitted each month, corresponding to about 45 applications per day. Figure 6 also shows that 8753 applications for B or C buildings, more than 90 % of the overall set for L'Aquila municipality buildings (9439 out of 10,430 applications), had been submitted to Fintecna by March 2010, ten months after enacting (OPCM no. 3779 2009).

The number of applications per month checked and approved by ReLUIIS, as well as those requiring clarifications, is shown in Fig. 7a, b. By March 2013 (when the *Filiera's* mandate ended) 9439 applications had been checked and 9348 approved. The remaining 91 did not complete the approval process because the clarifications required by the consortium were not provided in due time by practitioners. They were transferred to the special offices of L'Aquila and other municipalities which, at the end of the *Filiera's* activity, were specifically involved in the reconstruction process of buildings in historical centres.

A peak of 2799 applications checked by ReLUIIS was recorded in January 2010, with 2038 applications approved for financial contribution and the remaining 761 applications requiring clarifications. The table reported in Fig. 7 shows that 8664 applications (about 92 % of the overall set of 9439 applications submitted to Fintecna for the L'Aquila buildings) had been approved by ReLUIIS by September 2010, that is one year and three months after the *Filiera* activity began.



| Date           | Cumulative applications submitted |      |
|----------------|-----------------------------------|------|
|                | [-]                               | [%]  |
| September 2009 | 946                               | 10%  |
| October 2009   | 3,943                             | 42%  |
| November 2009  | 5,341                             | 57%  |
| December 2009  | 6,836                             | 72%  |
| January 2010   | 8,394                             | 89%  |
| March 2010     | 8,753                             | 93%  |
| September 2010 | 8,958                             | 95%  |
| March 2011     | 9,164                             | 97%  |
| September 2011 | 9,344                             | 99%  |
| September 2012 | 9,438                             | 100% |
| March 2013     | 9,439                             | 100% |

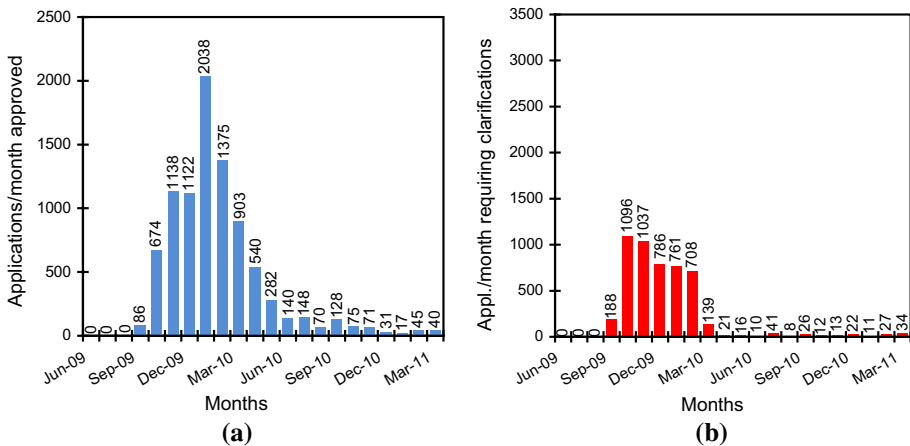
**Fig. 6** Applications/month submitted to Fintecna and cumulative applications submitted

The number of grants/month allocated by the L’Aquila municipality office after *Filiera* approval is reported in Fig. 8a. The total amount in euro of grants (cumulative trend) allocated by the L’Aquila municipality office until September 2013 (five months after the *Filiera*’s mandate ended) is reported in Fig. 8b and the relevant table.

The graph shows that the grants related to B or C buildings were allocated for 8467 applications (about 90 % of the overall applications for funding, 9439) within 1 year and 3 months after that the OPCM no. 3779 (2009) was issued (i.e. September 2010). In the first quarter of 2010 the most significant fraction of the overall grant was allocated, with an average of 2000 grants/month, corresponding to about 65 grants/day. The total amount of public funds allocated for buildings with usability rating B or C in L’Aquila municipality was, in September 2013, €534,359,872.00 (with 450 million euros, corresponding to 90 % of the total grant, allocated by September 2010).

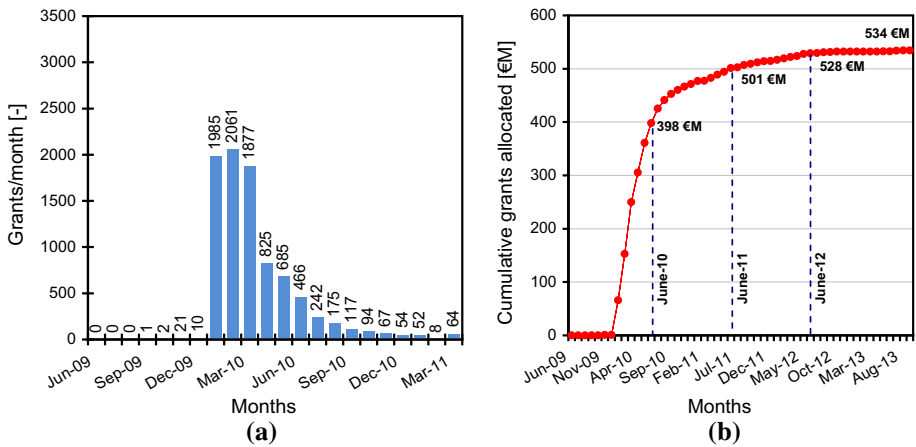
### 4.2 Repair and local strengthening interventions

According to OPCM no. 3779 and the relevant Annex (2009), usability recovery of B or C buildings can be pursued by interventions aimed at: (1) removing dangerous conditions and recovering the original seismic safety; (2) repairing structural and non-structural damaged



| Date           | Cumulative applications approved |     |
|----------------|----------------------------------|-----|
|                | [#]                              | [%] |
| September 2009 | 86                               | 1%  |
| October 2009   | 760                              | 8%  |
| November 2009  | 1,898                            | 20% |
| December 2009  | 3,020                            | 32% |
| January 2010   | 5,058                            | 54% |
| March 2010     | 7,336                            | 78% |
| September 2010 | 8,664                            | 92% |
| March 2011     | 8,923                            | 95% |
| September 2011 | 9,133                            | 97% |
| September 2012 | 9,289                            | 98% |
| March 2013     | 9,348                            | 99% |

**Fig. 7** Applications/month approved by ReLUI5 (a), applications/month requiring clarification by ReLUI5 (b), and cumulative applications approved



| Date           | Cumulative grants allocated |            | Cumulative Grant allocated |
|----------------|-----------------------------|------------|----------------------------|
|                | [-]                         | [%]        | [€]                        |
| December 2009  | 34                          | 0%         | 940,492.17                 |
| January 2010   | 2,019                       | 21%        | 65,740,003.67              |
| February 2010  | 4,080                       | 43%        | 152,536,797.89             |
| March 2010     | 5,957                       | 63%        | 246,860,149.31             |
| May 2010       | 6,782                       | 72%        | 305,103,562.19             |
| June 2010      | <b>7,933</b>                | <b>84%</b> | <b>398,031,913.50</b>      |
| July 2010      | 8,175                       | 87%        | 425,448,022.90             |
| September 2010 | 8,467                       | 90%        | 452,717,028.51             |
| March 2011     | 8,806                       | 93%        | 482,756,140.19             |
| June 2011      | <b>8,967</b>                | <b>95%</b> | <b>501,343,472.94</b>      |
| September 2011 | 9,048                       | 96%        | 509,215,730.00             |
| June 2012      | <b>9,211</b>                | <b>98%</b> | <b>528,788,649.11</b>      |
| September 2012 | 9,234                       | 98%        | 531,004,202.30             |
| March 2013     | 9,247                       | 98%        | 532,259,802.15             |
| September 2013 | 9,281                       | 98%        | 534,359,872.31             |

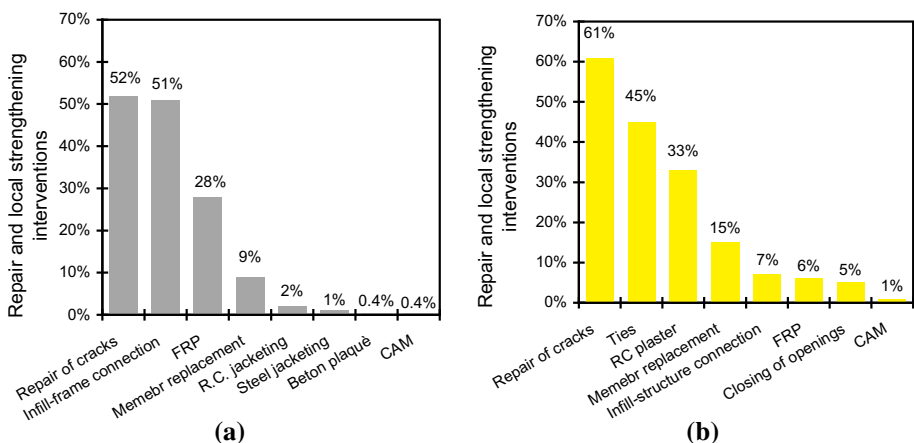
**Fig. 8** Applications/month granted by the L'Aquila municipality (a), cumulative grants (b)

elements; (3) reducing building vulnerability by local strengthening interventions. In particular, the class of repair interventions involves the following categories: repair of damaged non-structural parts and relevant finishing works; local repair of damaged structural members; demolition and reconstruction of fully damaged or unsafe non-structural or secondary structural elements (i.e. interior or exterior infills, outdoor curtains, heavy plasters, fireplaces and chimney-pots, porches, eaves, repair of damaged facilities, local repair of structural elements, etc.).

Local strengthening interventions aim to remove the main structural deficiencies which may cause unfavourable collapse mechanisms in the case of a seismic event. Thus they allow the seismic capacity of one or more under-designed components to be increased without affecting the overall behaviour of the structure. This strategy represents a swift cost-effective improvement in seismic performance; in accordance with Italian seismic code, only the capacity increase of local components need be assessed. There is no requirement to run a global analysis to check the attainment of a specific performance level, provided that global mass and structural stiffness are not significantly affected by the

local strengthening intervention (Fracadore et al. 2015). OPCM no. 3779 and the relevant Annex (2009) specifically addressed the use of suitable local strengthening interventions for RC and masonry structures. In particular, it is recommended to adopt local interventions aimed at increasing the shear capacity of exterior beam column joints (unconfined joints) and increasing the ductility of single members in RC structures. In the case of masonry structures, it is recommended to adopt interventions to: increase the effectiveness of the connections between masonry walls and slabs or roofs and between orthogonal walls (e.g. by inserting ties or equivalent systems); eliminate the horizontal thrusts on masonry walls produced by roofs, arches or vaults; strengthen masonry areas surrounding openings (e.g. by replacement of existing lintels). The types of local strengthening techniques and their frequency found in the design drawings related to the applications presented by practitioners for B or C buildings are separately reported for RC and masonry structures in Fig. 9a, b, respectively. Analysis of the data collected refers to 1218 RC buildings and 1116 masonry buildings. In particular, the design of interventions for the usability recovery of RC buildings involved repair and local strengthening interventions in 903 projects (74 % of the RC building dataset) while in the remaining 315 projects (26 %) only repairs were carried out. In the case of masonry buildings, 969 projects (87 % of the masonry building dataset) involved repair and local strengthening interventions and 147 (13 %) only repairs. In Fig. 9a, b the frequency of the main types of interventions is reported; because more than one type of intervention was adopted on each building, the sum of percentages clearly exceeds 100 %.

Figure 9a shows that the repair of cracks was the most commonly used type of repair intervention (52 % of projects) for RC buildings. In the local strengthening category several techniques were adopted in the design: infill-frame connections, using FRP grids bonded with a cement-based mortar or steel profiles, to avoid out-of-plane collapse, as illustrated in Fig. 10, (DPC (Civil Protection Department) and ReLUIIS (Laboratories University Network of Seismic Engineering) 2011). FRP-based interventions (Fig. 11) were employed to increase the shear capacity of unconfined joints (exterior beam-column joints), the shear capacity of beams at ends, the deformation capacity in the critical zones (confinement, mainly adopted at column ends), (Di Ludovico et al. 2008a, b; Del Vecchio et al. 2014, 2015; Fracadore et al. 2015). Further techniques included replacement of



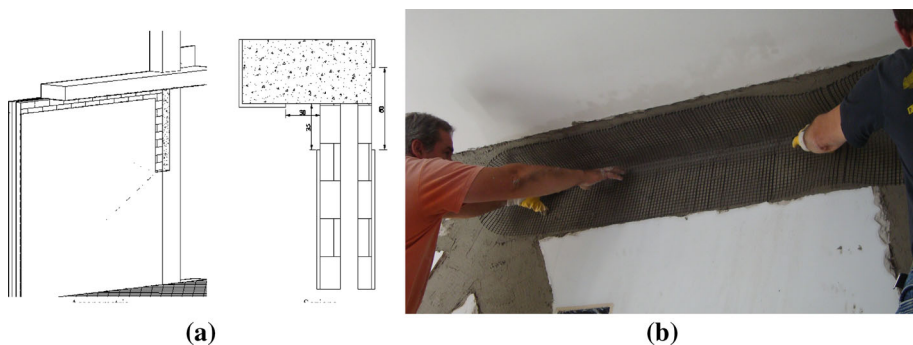
**Fig. 9** Repair and Local Strengthening Interventions: RC structures (a), masonry structures (b)

members; RC jacketing or steel jacketing of members to increase the shear and/or flexural capacity of members and the deformation capacity in the critical zones; steel plates to increase the flexural capacity of beams (i.e. *beton plaqué*); prestressed steel ribbon (CAM) as alternative technique to FRP laminates. It is worth noting that in 621 projects (51 % of the RC building dataset) practitioners planned, amongst others, interventions to avoid out-of-plane collapse of interior or exterior infills.

Figure 9b shows that for masonry buildings the repair of cracks was the most commonly adopted repair intervention (61 % of projects). The most widely used techniques to achieve this objective were injections (with mortar or epoxy-based resins) with or without further application of an FRP grid bonded with a cement-based mortar; and the local dismantling and rebuilding method (known as *scuci-cuci*) to restore the wall continuity along cracking lines (replacement of damaged elements with new ones, re-establishing structural continuity) and to recover heavily damaged parts of masonry walls. Although adopted also in the case of masonry buildings, intervention involving infill-structure connections were less frequent than in the case of RC buildings; they were designed only in 7 % of the projects to avoid out-of-plane collapse of internal partitions. In the category of local strengthening interventions the most commonly adopted solutions were the insertion of ties (i.e. steel, RC or tie rods, Fig. 12) to avoid out-of-plane mechanisms of walls (45 % of projects) and in-plane strengthening of masonry walls by means of RC plaster (33 % of projects). In the latter case, interventions extended to several parts of the buildings were treated as global strengthening interventions and they required global analysis of the structure with the safety index assessment in the *ante* and *post* intervention configuration. The demolition and reconstruction of structural portions, FRP and CAM strengthening solutions as well as the closing of openings were also adopted as local strengthening solutions in a few projects.

#### 4.3 Repair and strengthening costs

The grant allocated for each application involves repair costs for applications related to CU and repair and local strengthening costs for applications related to CA and ID, respectively. According to OPCM no. 3779 (2009) and the relevant Annex (2009), the repair costs to restore the original conditions of damaged parts (structural or non-structural elements) are fully covered unless the relation between the damage and the earthquake is not demonstrated; the reimbursement for local strengthening interventions is allowed in CA or ID



**Fig. 10** Infill-frame connections by means of FRP grids bonded with a cement-based mortar: design drawing (a), in field application (b)



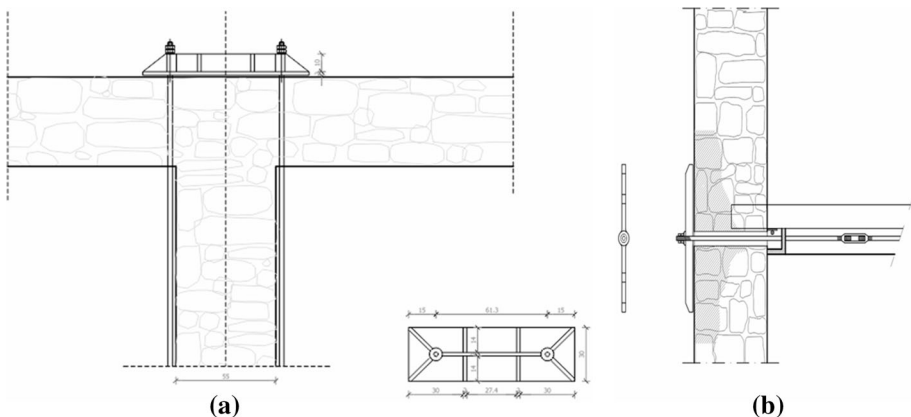


**Fig. 11** FRP-based interventions to increase the joint shear capacity of unconfined joints (a) and the deformation capacity in the critical zones of columns (b)

applications, with a maximum grant of €150/m<sup>2</sup> inclusive of VAT and practitioners’ fees for design and technical assistance.

The repair costs are inclusive of: building safety measures (in CA and ID applications only); demolition and removal including transportation costs and landfill disposal; repair interventions; testing of facilities; technical works for health and hygiene improvement; technical works to improve facilities; construction and safety costs; charges for the design and technical assistance of practitioners; furniture moving. Local strengthening costs are inclusive of strengthening interventions on structural and non-structural members (and relevant finishing works) and of charges for the design and technical assistance of practitioners.

The costs per square metre of the gross surface area related to 8294 applications (7600 applications for L’Aquila municipality and 694 for other municipalities) are summarised in Table 3 for ID, CA or CU applications. The costs reported in the table are representative of



**Fig. 12** Insertion of ties: plan view (a); elevation view (b)

the mean effective financial contribution granted after the *Filiera* checks and approval (i.e. costs paid out to owners after approval).

Table 3 reports costs inclusive of charges for the design and technical assistance of practitioners, but does not include VAT (10 % of costs for repair and local strengthening interventions and 20 % for other costs).

The repair unit costs related to applications of L'Aquila municipality were in each case higher than those related to the other municipalities, as expected according to the distance from the earthquake epicentre. By contrast, the costs related to local strengthening interventions (CA and ID applications) were much higher in the case of applications in other municipalities. In both cases the local strengthening unit costs were far below the maximum allowed according to OPCM no. 3779 (2009) (i.e. €150/m<sup>2</sup> inclusive of VAT and practitioners' fees for design and technical assistance). The mean unit costs for repair works on CU were €198.33/m<sup>2</sup> and €119.68/m<sup>2</sup> for L'Aquila and for other municipalities, respectively.

In order to provide information on the grant related to each building rather than each application, the data for ID or CA and relevant CU (i.e. condominiums consisting of common areas and residential units belonging to the same building) were then analysed. The 7600 applications for L'Aquila concern 2706 buildings, i.e. 1452 ID and 1254 condominiums. The 1254 condominiums comprised 4894 CU and, on average, 3.9 CU applications were submitted for each condominium. The 694 applications related to other municipalities corresponded to 450 buildings (332 ID and 118 condominiums comprising 244 CU, on average 2.1 CA applications being submitted per condominium).

The frequency distributions of the cost per square metre relevant to buildings in L'Aquila and in the other municipalities are reported in Figs. 13 and 14, respectively. In particular, the number of buildings belonging to different classes of costs (with intervals of €100/m<sup>2</sup>) is reported, as well as statistics concerning costs. The building gross surface area was used for this cost analysis. In the case of condominiums the costs per square metre were computed as the sum of the costs related to the CA application and those related to the relevant CU applications divided by the building gross surface area:

$$\left(\frac{\text{€}}{\text{m}^2}\right)_{\text{condominium}} = \frac{(\text{€})_{\text{CA}}}{S_c} + \sum_{i=1}^n \left[ \frac{(\text{€}/\text{m}^2)_{(\text{CU})i} \cdot (S)_{(\text{CU})i}}{S_c} \right] \quad (1)$$

where  $(\text{€}/\text{m}^2)_{\text{condominium}}$  is the cost per square metre for a condominium;  $(\text{€})_{\text{CA}}$  is the cost with respect to the common areas, CA application;  $(\text{€}/\text{m}^2)_{(\text{CU})i}$  is the cost per square

**Table 3** Mean repair and local strengthening costs related to ID, CA, and CU of L'Aquila municipality and other municipalities (buildings with usability rating B or C)

| Municipality                            | Type of application | No. of applications | Repair costs        | Local strengthening costs | Repair + Local strengthening costs |
|-----------------------------------------|---------------------|---------------------|---------------------|---------------------------|------------------------------------|
| (–)                                     | (–)                 | (–)                 | (€/m <sup>2</sup> ) | (€/m <sup>2</sup> )       | (€/m <sup>2</sup> )                |
| L'Aquila (7600 applications)            | ID                  | 1452                | 174.03              | 43.41                     | 217.44                             |
|                                         | CA                  | 1254                | 124.12              | 48.81                     | 172.93                             |
|                                         | CU                  | 4894                | 198.33              | –                         | 198.33                             |
| Other municipalities (694 applications) | ID                  | 332                 | 163.19              | 77.21                     | 240.40                             |
|                                         | CA                  | 118                 | 95.57               | 76.34                     | 171.91                             |
|                                         | CU                  | 244                 | 119.68              | –                         | 119.68                             |

metre for the  $i$ -th residential unit belonging to that condominium;  $S_{(CU)i}$  is the gross surface area of the CU;  $S_C$  is the gross surface area of the building.

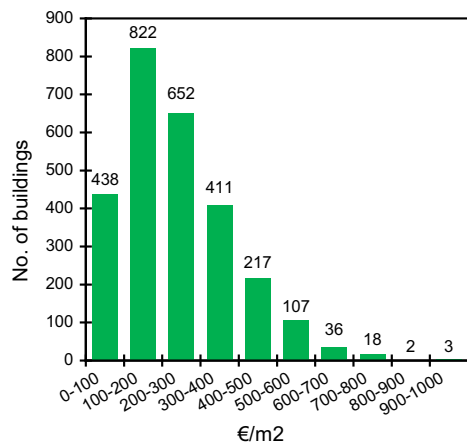
The mean and median unit costs of repair and strengthening interventions for buildings in L’Aquila were €240.19/m<sup>2</sup> and €213.57/m<sup>2</sup>, respectively; in the case of buildings in other municipalities they were €237.30/m<sup>2</sup> and €214.62/m<sup>2</sup>, respectively. The mean grant allocated for each building in L’Aquila and other municipalities was €159,165.09 and €97,434.25, respectively; the mean surface area of buildings was 697.09 and 440.80 m<sup>2</sup>, respectively.

The mean unit costs of repair and strengthening interventions calibrated on RC or masonry structures of L’Aquila municipality are summarised in Table 4, the data referring to 2497 buildings (i.e. 1598 RC and 899 masonry buildings). Table 4 shows that the mean total grant (sum of unit costs for repairs and strengthening interventions) allocated for masonry buildings was about 24 % greater than that for RC buildings; in particular, for masonry building unit costs for both repair and local strengthening were 15 and 50 % higher than those for RC buildings, respectively. Thus, although it was not fully reached, the upper bound of €150/m<sup>2</sup> to reduce the vulnerability of slightly damaged constructions was better exploited in the case of masonry buildings.

The costs per square metre of the sum of repair and local strengthening costs pertinent to RC or masonry buildings in L’Aquila are reported in Fig. 15a, b. The mean unit costs of repair and strengthening interventions for RC and masonry buildings in L’Aquila were €217.76/m<sup>2</sup> and €285.13/m<sup>2</sup>, respectively, corresponding to mean grants of €197,725.54 and €102,806.55, respectively. The mean surface area was 870.70 m<sup>2</sup> for RC and 368.50 m<sup>2</sup> for masonry buildings. The frequency distributions of costs are very similar for the two types of buildings, apart from the histogram peaks which were attained in the cost range €100–200/m<sup>2</sup> in the case of RC buildings (including about 33 % of the dataset) and in the cost range €200–300/m<sup>2</sup> in the case of masonry buildings (including about 27 % of the dataset).

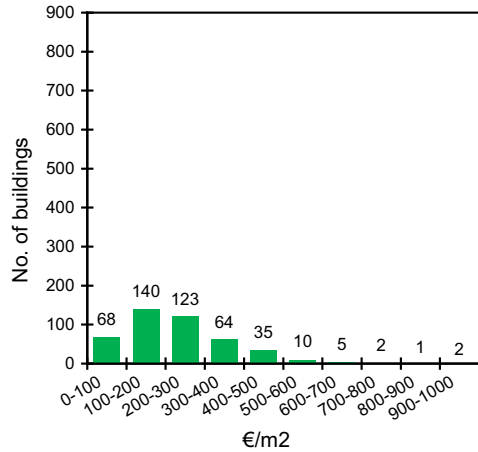
Furthermore, the rate of each cost type (i.e. repair, strengthening interventions and professional fees for the design and technical assistance of practitioners) is reported in

| Statistics                                      |                |
|-------------------------------------------------|----------------|
| No. of buildings [-]                            | 2,706          |
| Mean [€/m <sup>2</sup> ]                        | 240.19         |
| Median [€/m <sup>2</sup> ]                      | 213.57         |
| Minimum [€/m <sup>2</sup> ]                     | 8.95           |
| Maximum [€/m <sup>2</sup> ]                     | 987.83         |
| Range [€/m <sup>2</sup> ]                       | 978.88         |
| 16 <sup>th</sup> percentile [€/m <sup>2</sup> ] | 99.41          |
| 84 <sup>th</sup> percentile [€/m <sup>2</sup> ] | 383.23         |
| Standard dev. [€/m <sup>2</sup> ]               | 146.84         |
| CoV [%]                                         | 61             |
| Asymmetry [-]                                   | 1              |
| Kurtosis [-]                                    | 1              |
| Total grant [€]                                 | 430,700,731.59 |
| Mean grant [€]                                  | 159,165.09     |
| Mean surface area [m <sup>2</sup> ]             | 697.09         |



**Fig. 13** Sum of repair and local strengthening costs on buildings in L’Aquila (buildings with usability rating B or C)

| Statistics                                      |               |
|-------------------------------------------------|---------------|
| No. of buildings [-]                            | 450           |
| Mean [€/m <sup>2</sup> ]                        | 237.30        |
| Median [€/m <sup>2</sup> ]                      | 214.62        |
| Minimum [€/m <sup>2</sup> ]                     | 18            |
| Maximum [€/m <sup>2</sup> ]                     | 999.68        |
| Range [€/m <sup>2</sup> ]                       | 981.91        |
| 16 <sup>th</sup> percentile [€/m <sup>2</sup> ] | 104.07        |
| 84 <sup>th</sup> percentile [€/m <sup>2</sup> ] | 365.33        |
| Standard dev. [€/m <sup>2</sup> ]               | 142.32        |
| CoV [%]                                         | 60            |
| Asymmetry [-]                                   | 1             |
| Kurtosis [-]                                    | 4             |
| Total grant [€]                                 | 43,845,412.87 |
| Mean grant [€]                                  | 97,434.25     |
| Mean surface area [m <sup>2</sup> ]             | 440.80        |



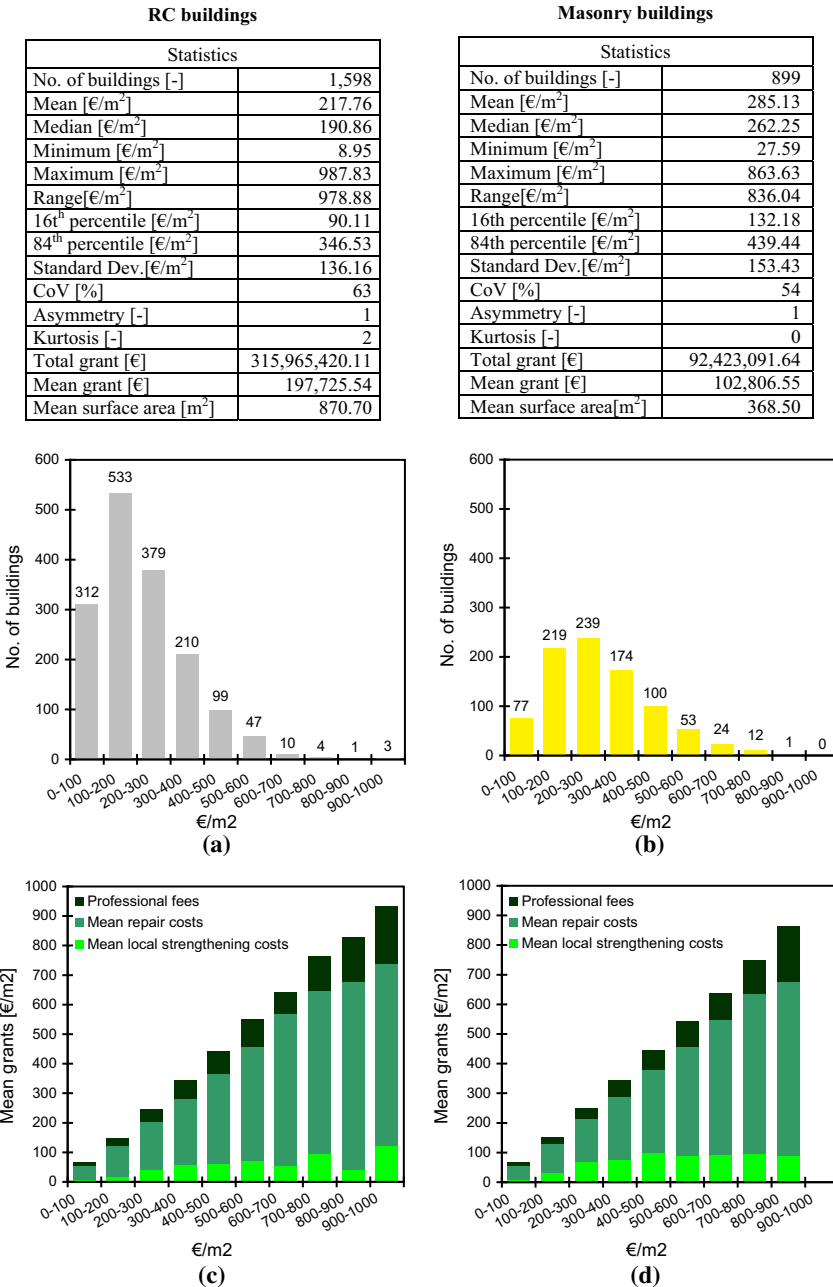
**Fig. 14** Sum of repair and local strengthening costs on buildings in the other municipalities (buildings with usability rating B or C)

Fig. 15c, d for RC and masonry buildings, respectively. The mean value of each cost type is reported for each class of costs with a range of €100/m<sup>2</sup>; the detailed data are summarised in Table 5. The graphs show that the mean grant is strongly affected by the repair costs, which represent the most significant ratio of the mean grant (on average 71 % of the mean grant for RC buildings and 66 % for masonry buildings). The average percentage rate of local strengthening costs with respect to the mean grant was about 12 % for RC and 18 % for masonry buildings. Professional fees represented on average about 17 and 16 % of the mean grant, respectively. Mean grants exceeding €600/m<sup>2</sup> were attained in very few cases (i.e. 18 RC buildings and 37 masonry buildings). From Table 5 it may be determined that, in the class of grants lower than €600/m<sup>2</sup>, the ratio of repair costs to local strengthening intervention costs was on average 5.3 and 3.5 for RC and masonry buildings, respectively. Figure 15c, d clearly show that, even for a homogeneous class of usability rating B or C, the impact of repair costs can vary significantly.

For RC and masonry buildings in L’Aquila, the median, 16th and 84th percentile of repair costs as a function of construction age and number of storeys are reported in Figs. 16 and 17, respectively. The data concern 1460 RC buildings and 830 masonry buildings (out of 1598 and 899) for which both construction age and number of storeys are available. Figure 16a, c shows that the median repair costs decreased with the construction age. By contrast, a pseudo-constant trend was observed in the case of masonry buildings (see Fig. 16b, d). Similarly Fig. 17a, c shows that, except for RC buildings with more than

**Table 4** Mean repair and local strengthening costs related to RC and masonry buildings in L’Aquila (buildings with usability rating B or C)

| Type of structure (-) | No. of buildings (-) | Repair costs (€/m <sup>2</sup> ) | Local strengthening costs (€/m <sup>2</sup> ) | Repair + local strengthening costs (€/m <sup>2</sup> ) |
|-----------------------|----------------------|----------------------------------|-----------------------------------------------|--------------------------------------------------------|
| RC                    | 1598                 | 183.76                           | 33.90                                         | 217.76                                                 |
| Masonry               | 899                  | 216.81                           | 68.32                                         | 285.13                                                 |



**Fig. 15** Sum of repair and local strengthening costs for buildings in L’Aquila (buildings with usability rating B or C): mean grant for RC buildings (a); mean grant for masonry buildings (b); cost of repairs, local strengthening and professional fees for RC buildings (c); cost of repairs, local strengthening and professional fees for masonry buildings (d)

**Table 5** Number of buildings, mean grant, repair costs, local strengthening costs, and practitioners' fees for design and technical assistance related to RC and masonry buildings belonging to several application classes (buildings with usability rating B or C)

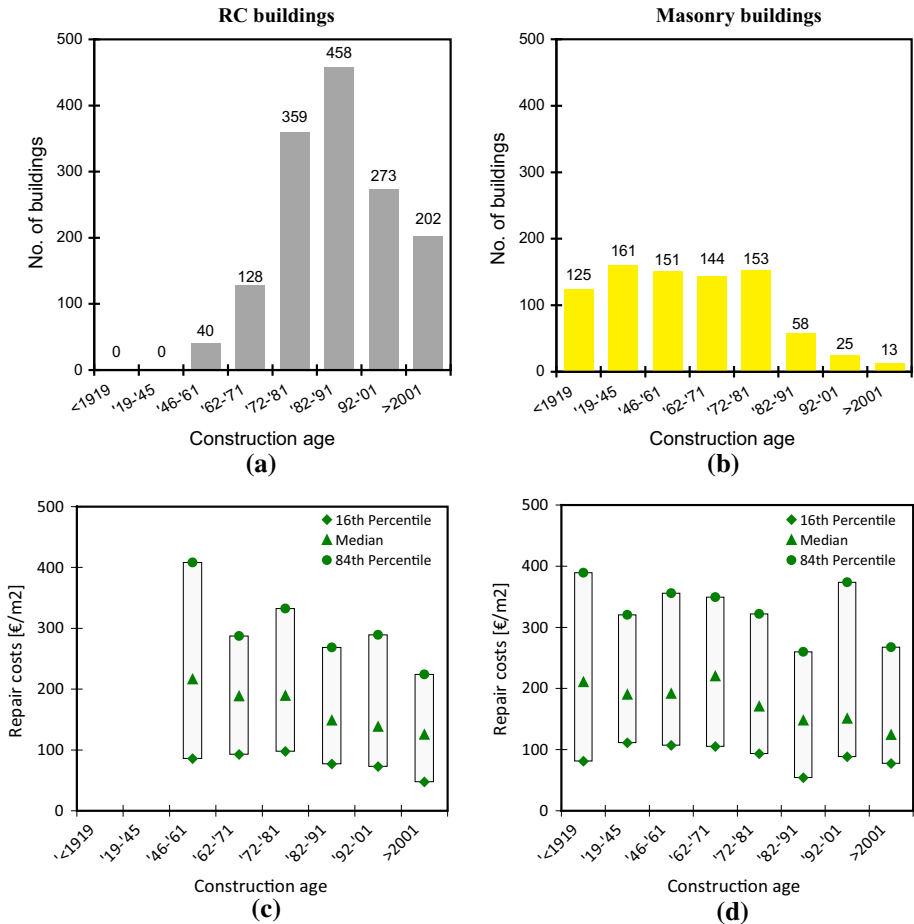
| Municipality | Type of structure | Grant range         | No. of buildings | Mean grant          | Repair costs        | Local strengthening costs | Professional fees   |
|--------------|-------------------|---------------------|------------------|---------------------|---------------------|---------------------------|---------------------|
| (–)          | (–)               | (€/m <sup>2</sup> ) | (–)              | (€/m <sup>2</sup> ) | (€/m <sup>2</sup> ) | (€/m <sup>2</sup> )       | (€/m <sup>2</sup> ) |
| L'Aquila     | RC                | 0–100               | 312              | 66.40               | 50.49               | 6.05                      | 9.86                |
|              |                   | 100–200             | 533              | 148.73              | 105.30              | 19.07                     | 24.37               |
|              |                   | 200–300             | 379              | 245.63              | 164.00              | 40.11                     | 41.52               |
|              |                   | 300–400             | 210              | 342.99              | 224.40              | 57.51                     | 61.08               |
|              |                   | 400–500             | 99               | 441.82              | 303.58              | 61.68                     | 76.57               |
|              |                   | 500–600             | 47               | 550.84              | 384.76              | 72.47                     | 93.61               |
|              |                   | 600–700             | 10               | 642.38              | 515.73              | 54.61                     | 72.04               |
|              |                   | 700–800             | 4                | 762.92              | 551.35              | 94.22                     | 117.34              |
|              |                   | 800–900             | 1                | 828.40              | 638.26              | 40.13                     | 150.00              |
|              | 900–1000          | 3                   | 934.00           | 615.94              | 122.43              | 195.62                    |                     |
|              | Masonry           | 0–100               | 77               | 65.84               | 47.19               | 7.66                      | 10.99               |
|              |                   | 100–200             | 219              | 152.00              | 96.78               | 32.76                     | 22.46               |
|              |                   | 200–300             | 239              | 249.59              | 144.81              | 68.63                     | 36.15               |
|              |                   | 300–400             | 174              | 344.79              | 215.10              | 75.90                     | 53.79               |
|              |                   | 400–500             | 100              | 444.62              | 280.76              | 98.94                     | 64.92               |
|              |                   | 500–600             | 53               | 542.51              | 366.56              | 90.60                     | 85.35               |
|              |                   | 600–700             | 24               | 638.91              | 455.59              | 92.24                     | 91.08               |
|              |                   | 700–800             | 12               | 748.10              | 540.04              | 96.36                     | 111.71              |
|              |                   | 800–900             | 1                | 863.63              | 584.25              | 90.74                     | 188.63              |
| 900–1000     |                   | 0                   | 0.00             | 0.00                | 0.00                | 0.00                      |                     |

seven storeys (only 5 buildings), the median repair costs increase with the number of storeys while they do not significantly affect the median repair cost trend in the case of masonry buildings (Fig. 17b, d).

Both Figs. 16 and 17 show a wide range of costs between the 16th and 84th percentile. This confirms that other structural characteristics such as the quality of the design and execution procedures, the plan and elevation regularity may strongly affect the seismic performance of existing buildings and hence the funds required for repairs.

## 5 Conclusions

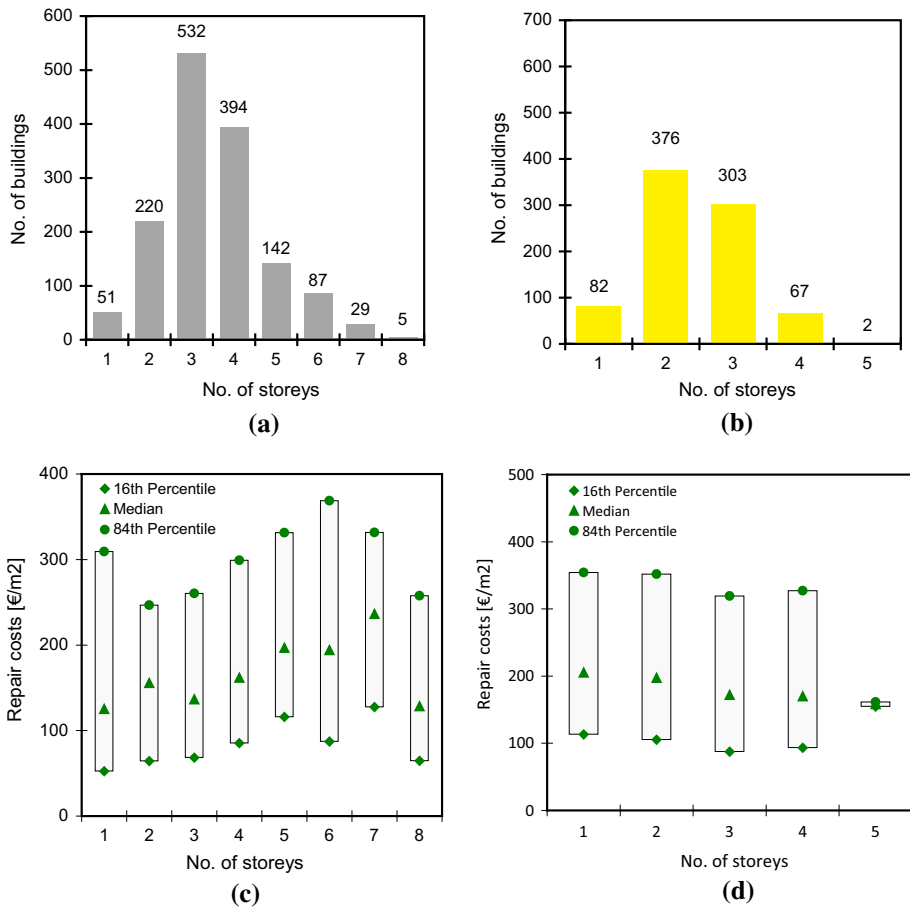
The financial reconstruction model for residential buildings outside the historical centres after the 2009 L'Aquila earthquake was regulated by Italian Government ordinances, specifically issued to enable rapid re-occupancy of damaged buildings. Accordingly, the repair costs of the damaged buildings were fully covered by public funds, while different upper bounds were established for the grant to support additional strengthening intervention costs. These upper bounds were calibrated on the usability assessment rating of the buildings. A commission, the *Filiera*, was entrusted by the government to scrutinise, from



**Fig. 16** Buildings with usability rating B or C: number of RC buildings as a function of construction age (a), number of masonry buildings as a function of construction age (b), repair costs for RC buildings (c), repair costs for masonry buildings (d)

the administrative, technical and economic angle, the applications submitted by homeowners for state grants.

The applications for funding concerned 5775 buildings (3564 buildings of usability rating B or C and 2211 buildings of usability rating E). In order to accelerate the recovery process, so-called “light damage” reconstruction relevant to less damaged buildings (B or C usability rating) started prior to “heavy damage” reconstruction of severely damaged or collapsed buildings (E usability rating). More than 90 % of the applications for the “light damage” reconstruction of L’Aquila municipality had been submitted by March 2010 (twelve months after the earthquake and ten months after enacting OPCM no. 3779); the approval process and the relevant grant allocation had been completed for 90 % of the applications by September 2010. In all, this accounted for 450 million euros out of 534 million euros, i.e. total public funds available for buildings with usability rating B or C in L’Aquila.



**Fig. 17** Buildings with usability rating B or C: number of RC buildings as a function of number of storeys (a), number of masonry buildings as a function of number of storeys (b), repair costs for RC buildings (c), repair costs for masonry buildings (d)

Mean repair costs per square metre for condominium units, including fees for design and the technical assistance of practitioners, and not including VAT, were €198.33/m<sup>2</sup> and €119.68/m<sup>2</sup> for buildings in L’Aquila and other municipalities, respectively.

The mean grant per square metre of the gross surface area for repair and strengthening interventions for buildings in L’Aquila municipality (2706 buildings) was €240.19/m<sup>2</sup> corresponding to a mean grant of €159,165.09 per building (mean surface area of 697.09 m<sup>2</sup>). For buildings in other municipalities (450 buildings) the mean unit cost was €237.30/m<sup>2</sup>, corresponding to a mean grant of €97,434.25 per building (mean surface area of 440.80 m<sup>2</sup>).

Our analysis of buildings in L’Aquila municipality showed that the unit cost for repairs and local strengthening interventions on masonry buildings was on average about 24 % higher than that for RC buildings (€285.13/m<sup>2</sup> versus €217.76/m<sup>2</sup> corresponding to a mean grant of €102,806.55 and a mean gross surface area of 368.50 m<sup>2</sup> for masonry buildings, and a mean grant of €197,725.54 and a mean gross surface area of 870.70 m<sup>2</sup> for RC



buildings). The local strengthening unit costs were far lower than the maximum envisaged under OPCM no. 3779 (i.e. €150/m<sup>2</sup>), on average equal to €33.90/m<sup>2</sup> and €68.32/m<sup>2</sup> for RC and masonry buildings, respectively. Finally, the construction age and the number of storeys affected the size of the grant more significantly for RC buildings than for masonry buildings.

Any judgement or assessment of the effectiveness of the financing model and its possible improvements are out of the scopes of this paper.

**Acknowledgments** The activity reported in the paper were carried out in the framework of contracts between ReLUIS and the Government Institutions in charge of the reconstruction of L'Aquila and other municipalities hit by the earthquake of April 6, 2009. The collaboration of Fintecna and Cineas is acknowledged as partners of ReLUIS in the activities described in the paper. This study was partially performed in the framework of the PE 2014–2016 joint programme DPC-ReLUIS.

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