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RECONSTRUCTION MODEL OF RESIDENTIAL BUILDINGS IN THE HISTORICAL CENTERS OF THE CRATER MUNICIPALITIES AFTER L'AQUILA 2009 EARTHQUAKE

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Abstract

The reconstruction process of residential buildings damaged by L'Aquila 2009 earthquake initially involved buildings outside historical centres and then, starting from August 2012, residential buildings in historical centres. The reconstruction model related to buildings in historical centres was developed by two special offices, involved in the reconstruction process of L'Aquila municipality and other 56 municipalities, respectively. Both special offices introduced new procedures to manage the reconstruction based on a parametric model to define the maximum public grant to repair and strengthen the damaged buildings in historical centres. The new model was necessary to deal with the reconstruction of historical centres mainly characterized by old masonry building aggregates with a cultural and architectural heritage value. The parametric model defined by the Special Reconstruction Office of the Crater Municipalities - USRC - is illustrated in the paper. The model allows to evaluate the maximum public grant on the basis of both the damage detected after the seism and the building vulnerability. Several potential grant increase to preserve the artistic and architectonic assets of historical buildings are also included in the model. The paper illustrates the main aspects of the parametric model along with the preliminary analyses of the public grant released up to April 2016.

Keywords: reconstruction, historical centres, residential buildings, public grants, repair costs.

1. Introduction

Two different phases can be clearly distinguished in the reconstruction process after the L'Aquila 2009 earthquake. A first phase (the so-called “Emergency Phase”) involved the reconstruction of residential buildings outside historical centres; the reconstruction policy was regulated by Law 77/2009 [1] and several Ordinances of the President of the Council of Ministers (OPCM). At this stage the financial strategy of the Italian government was to fully cover the repair work costs to restore the usability of damaged buildings; furthermore, different thresholds were defined for strengthening interventions as a function of the usability rating of each building. The usability rating was determined by proper post-earthquake field inspections carried out by team of surveyors; the AeDES survey form (Baggio et al. 2007 [2]) was adopted as a tool for the seismic damage and usability assessment. According to the AeDES survey form, the buildings can be classified into the following categories: A. Usable building (slightly damaged, can keep on housing the functions to which it was dedicated); B. Building usable only after short term countermeasures (buildings with limited or no structural damage but with severe non-structural damage); C. Partially usable building (buildings with limited or no structural damage but with severe non-structural damage located in a part of the building); D. Building to be re-inspected (due to atypical damage scenario 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 for external risk only.

For each building the repair and strengthening works and relevant costs were determined by practitioners engaged by owners. A proper team, called "Filiera" [3] was set up to oversee these project from the administrative, technical and economic angle and to deal with the numerous applications for funding. At the end of this reconstruction phase, funding applications related to 5,775 residential buildings outside the historical centre of L'Aquila and other municipalities were examined and approved by the Filiera. The total amount for residential buildings outside the historical centre of L'Aquila municipality allocated until September 2013 was about 2,1 billion and the total amount due to the activity of the Filiera can be estimated of the order of 2.6 billion euros. Details about this first phase of the reconstruction process can be found in Di Ludovico et al. 2016a,b [4],[5].

The second phase of the reconstruction process (the so-called “Post-Emergency Phase”) involved historical centres of L'Aquila and other 56 municipalities; the reconstruction policy was regulated by Law 134/2012 [6], which introduces a parametric model to determine the maximum public grant eligible to restore the usability of damaged buildings. The financial strategy of the Italian government was to fully cover not only the repair and strengthening costs to restore the usability of damaged buildings but also to establish some extra public funds to preserve the cultural and architectural heritage value of these buildings [7].

A new reconstruction model defined on the basis of new procedures was necessary in order to deal with the reconstruction of old masonry building aggregates (i.e. groups of masonry buildings to form complex building agglomerates) with a cultural and architectural heritage value. Historical masonry buildings incorporate structural elements, such as arches, domes, vaults and irregular shaped-columns, with earthquake-response, which is difficult to simulate and predict in numerical analyses. The seismic retrofitting measures in these cases are not straightforward because they should encompass efficiency and safety, compatibility with existing materials, non-invasive scheme and reversibility, as well as durability of the intervention. The built heritage conservation requires to apply minimally invasive techniques, but capable to ensure a significant increase of seismic safety. Operating on such a context involves a high level of uncertainty to define the state of preservation of structural and non-structural elements. It is particularly difficult to fully predict the exact amount of works to be performed during the design phase, therefore implementing a procedure capable of guaranteeing work in progress variants with a quick tool becomes essential, also ensuring expenditure control in the meantime.

Given the complex spatial and morphological structure of the territory, special rules for reconstruction have been issued for historical centres. The management of such stage of the reconstruction process was assigned to two special offices: The Special Reconstruction Office of L'Aquila - USRA - for the reconstruction process of buildings in historical centres of L'Aquila, and the Special Reconstruction Office of the Crater Municipalities - USRC - for the reconstruction process of buildings in historical centres of other municipalities (56 municipalities in the area hit by the earthquake, the so called "crater", divided in 8 homogeneous areas with

8 relevant reconstruction offices, UTR, depending on USRC, see Fig. 1). The procedure and the reconstruction model defined by USRC are described in the following sections along with the preliminary data about the number of funding applications and relevant public grants.

Fig. 1 - Municipalities in the Abruzzo region under the management of the Special Reconstruction Office of the Crater Municipalities.

2. Reconstruction policy: the parametric model

The public funding needed to repair the private buildings in the 56 aforementioned historical centres (i.e. crater municipalities) is requested by the owner, who can be a delegate in case of multiple owners (typically in building aggregates). According to Law 134/2012 [6], the owner engages a practitioner, who is appointed to carry out the repair and strengthening construction executive project and all the data set essential to determine the funding amount threshold (namely *Allowable Grant, AG*). Indeed, the parametric model adopted by the USRC (the so called Integrated Model for the municipalities of the Crater, IMC model [8], [9]) for the approval of funding applications consists of two main steps: *i)* the computation of the *Allowable Grant* for the interventions by means of a suitable form specifically set up to quickly define the building vulnerability class and damage grade, the so called IMC form; *ii)* the definition of the executive project including quantities and materials costs for repair, strengthening intervention, energy efficiency upgrade.

The application for funding can be filled with reference to: a) Building Aggregates (namely BA); b) a portion of the BA with homogeneous characteristics, Aggregate Minimum Unit (namely AMU), see Fig. 2 (e.g. the aggregate depicted in such figure is analyzed by means of tree applications related to AMU 1, AMU 2 and AMU

3). The application for funding related to BA or AMU contains data related to one or more buildings (B) which consist of one or more dwellings (namely DW).

Fig. 2 - Building Aggregate (BA) and sub-units.

In the approval process, the cost estimate and the design drawings and technical reports related to BA or AMU are submitted by an online procedure to the UTR, which verifies if the restoration work costs are lower than *AG*. In this case, the funding request is approved via simplified check. This simplified check only involves: the administrative aspects; the consistency between the data used to fill the IMC form and to compute the *AG* and the actual buildings' characteristics and damage; the type of designed repair and strengthening interventions and relevant costs; the requested extra costs accounting for the cultural and architectural heritage; the seismic safety level attained by buildings after the strengthening works, and the correct use of the official prices list. In particular, the administrative aspects are carefully investigated focusing the attention on the ownership, the town planning compliance, and the compliance of the executive project with the Town Reconstruction Plans (urban planning tools properly defined to control and manage the reconstruction process of damaged towns, promoting the recovery and requalification of existing buildings and facilitating the execution of the intervention works) and/or other existing urban planning.

Thus, if the intervention costs are lower than *AG*, the simplified administrative procedure facilitates the final approval speeds up the process.

By contrast, in the case of extraordinary conditions (to be demonstrated by the practitioner engaged by owners) corresponding to funding request amount greater than *AG*, the executive project is overseen with a more accurate checking of technical and economic aspects.

Once the application for funding is approved, the approval form is transmitted to the public offices of the municipality concerned for transferring the financial contribution.

Finally, once the construction site starts, the grant is periodically delivered to the applicant according to project status report (the so-called *SAL*).

During the restoration works, the UTR surveyors control the correct use of the grant and its finalization through on-site inspections.

2.1 Allowable Grant

The *Allowable Grant*, *AG*, related to BA or AMU is determined according to the following procedure. In order to determine *AG*, it is necessary to compute the Intervention Unit Cost (*IUC*) related to each building, (*B*), the Conventional Cost (*CC*), and the Grant Increase Factors (*GIF*), see Fig. 3.

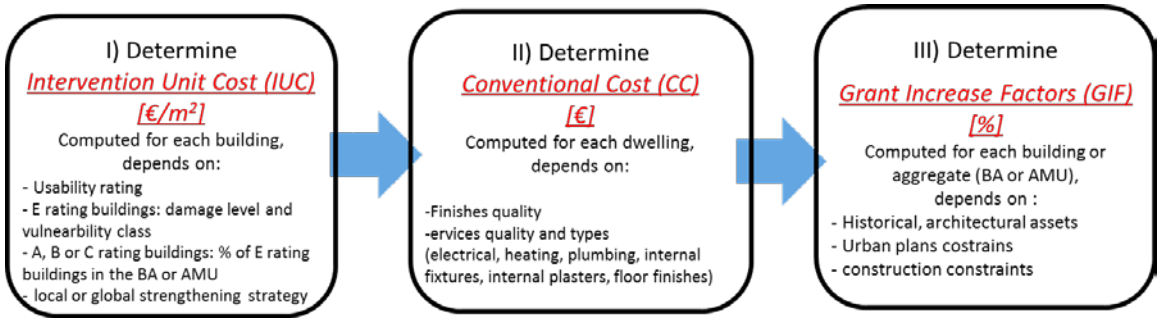


Fig. 3 - Steps to compute the Allowable Grant

- *Intervention Unit Cost (IUC)*

The Intervention Unit Cost (*IUC*) for each building of the aggregate depends on the usability rating of the building assessed in the first emergency phase. It also depends on the type of strengthening intervention selected by practitioners engaged by owners on the BA or AMU. It covers repair, strengthening and upgrading interventions. It is possible to select local strengthening interventions (only for BA or AMU with a significant ratio of buildings with usability rating A or B or C) or strengthening interventions aimed at achieving a BA or AMU seismic safety level greater than 60%NBS (New Building Standard, %NBS). In the latter case, for buildings with usability rating E (unusable building) the relevant *IUC* depends on the building vulnerability class and the damage detected on the building after the earthquake. Three vulnerability classes (namely low vulnerability "V1", medium vulnerability "V2", and high vulnerability "V3") and six damage levels (namely no damage "D0", light damage "D1", moderate "D2", medium "D3", heavy "D4", and very heavy "D5") have been assumed in order to determine the *IUC*, see Table 1. The damage levels are computed according to the same principles adopted to fill the AeDES form [2];the vulnerability classes are defined according to the following parameters: masonry quality; quality of connection between orthogonal walls; bearing walls spacing; roof types; horizontal structures quality; plan and vertical irregularity [9]. According to damage levels and vulnerability classes, four damage-vulnerability classes are defined (i.e. L0, L1, L2, L3) with relevant *IUC*. The *IUC* is expressed as euro per square meter of the overall surface; the *overall surface* is defined as the sum of the surface of each dwelling of the building and the 60% of non-dwellings surfaces (i.e. cellar, garage or common surfaces); the *overall surface* is measured without the wall thickness. The correlation between damage level and vulnerability classes as well as the relevant IUC are summarized in Table 1 and Table 2. Four damage-vulnerability levels, L_i, are defined with relevant IUC ranging between 700 €/m^2 and 1,270 €/m^2. The maximum amount is equal to the cost defined in the Abruzzo Region for social housing buildings [10],[11].

Table 1 - Correlation between damage, vulnerability class and IUC for buildings with usability rating E.

Damage level		**Vulnerability class**		
		V1	**V2**	**V3**
none	D0	L0	L0	L1
light	D1	L0	L1	L1
moderate	D2	L1	L1	L2
medium	D3	L1	L2	L3
heavy	D4	L2	L3	L3
very heavy	D5	L3	L3	L3

Table 2 - IUC grant for buildings with usability rating E.

Damage-Vulnerability	**IUC [€/m^2]**
L0	700
L1	1000
L2	1100
L3	1270

It is noted that a detailed analysis related to the reconstruction costs on the residential buildings outside the historical centres was performed in order to better calibrate the *IUC* grants [12].
In case of buildings with usability rating A, B, or C (i.e. buildings slightly damaged or with limited structural damage), the *IUC* is computed depending on: *i)* the percentage ratio of the overall surface of buildings with usability rating E into the BA or AMU, ρ_E; *ii)* the maximum damage level detected on E buildings belonging to BA or AMU. Thus, the *IUC* is determined as reported in Fig. 4 and it can vary from a minimum of 300 €/m^2 (A usability rating) or 500 €/m^2 (B usability rating) up to a maximum of 700 €/m^2 or 1,000 €/m^2 in the case A, B or C buildings in a BA or AMU with E rating buildings with a damage level L0 or with a damage level greater than L1. The minimum values are attained for ρ_E < 40% while the maximum ones for ρ_E > 70%; the IUC is computed by means of a linear interpolation for 40% <ρ_E < 70%.

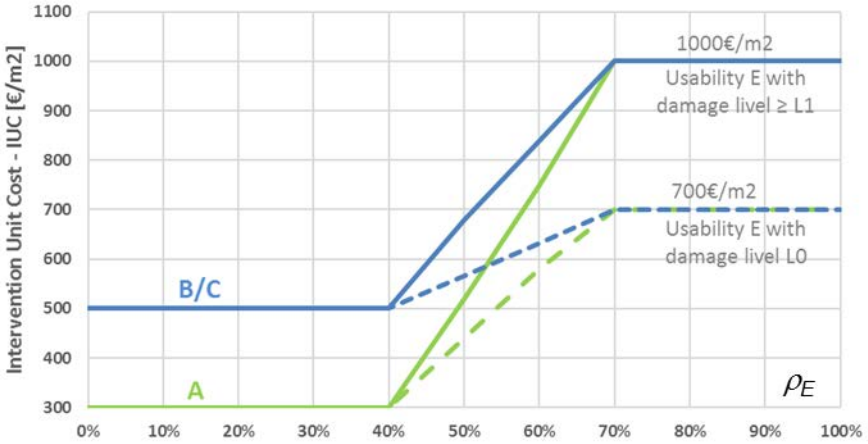


Fig. 4 - IUC for buildings with usability rating A, B, or C for AMU or BA with E buildings.

If local strengthening interventions are selected by practitioners rather than global strengthening ones, the IUC changes as follows: 250 €/m^2 for A usability rating buildings (it is not allowed if no E usability rating buildings occur in the BA or AMU); 400 €/m^2 for B or C usability rating buildings; 600 €/m^2 for E usability rating buildings. However, if no E rating buildings are found in the BA or AMU, the IUC is assumed equal to 0 €/m^2 or 400 €/m^2 for buildings with usability rating A, or B or C, respectively.

- *Conventional Cost (CC)*

The Conventional Cost (CC) is defined considering the presence of services, their quality, and the quality of finishes of each building dwelling according to the intended use.
A preliminary analysis of the AeDES survey forms confirmed the presence of old unused buildings with level of finishing and quality of services much different by current building standards. Therefore, a specific way to manage buildings with different levels of maintenance was deemed needful to be introduced: 6 categories of internal finishing and services have been distinguished. In lack of these, a percentage grant reduction coefficient, r_k, is applied. The categories and the relevant reduction factors are summarized in Table 3. Thus r_k varies between 0% and -26.5%.

Table 3. Percentage reduction coefficients, r_k, in case of finishing and services lacking.

Electrical	Heating	Plumbing	Internal fixtures	Internal plasters	Floor finishes
-5%	-4%	-2,5%	-4%	-4%	-7%

The percentage reduction coefficients, r_k are applied, for every building, separately for each dwelling, at the Intervention Unit Cost:

$$CC_j = \sum_{i=1}^{n} \left[S_i \cdot IUC_j \cdot \left(\left| 1 - \sum_k r_k \right| \right) \right] \quad (1)$$

Where CC_j is Conventional Cost for the j^{th} building in BA or AMU, S_i is the overall surface of the i^{th} dwelling in the j^{th} building and r_k are the reduction coefficients listed in Table 3.

- *Grant Increase Factors (GIF)*

Specific grant increase has been established accounting for the relevant characteristics of the Crater historical centres; such increases allow to manage particular conditions involving costs not included in the definition of the CC (as the presence of caves below the building or site achievable only through narrow streets).

Furthermore, grant increase have been also provided for integrated conservation of the historical, architectural, environmental, material and constructive values that express the organic unity of the original structural and architectural fabric.

These increases are specified into the agreement between USRC and the local office of Ministry of Cultural Heritage and can be used in case of preservation or restoration of specified architectural or structural elements as: worked stone, traditional roof tiles, vaults, original wooden roof structures.

There are two kinds of increases: applied to buildings and applied to aggregates. In the category related to buildings the following factors may be considered: *(a)* presence of valuable elements as masonry on sight, vaults, worked stones, that can attain percentage values up to 60% of CC [12]; *(b)* difficulty for siting in case of streets narrower than 3.5m; *(d)* removal of shores applied to buildings in danger of fault; *(e)* safety of parts considered "ruins" influencing the stability of the aggregate. In the category related to aggregates may be considered *(c)* increase for seismic local amplification. Furthermore, the allowable grant can increases, through detailed analysis, by the followings factor: *(f)* reduction of vulnerability of eventual caves below the aggregate*; (g)* restoration of damaged minor elements relevant for the usability of buildings; *(h)* interventions on ancillary elements belonging to aggregate but used by community (like yards) or for interventions on other elements, like contrast arches, fountains placed against external wall of the aggregate.

Underground natural or manmade caves are frequent in the Crater Area. These are often below the structures of public and private buildings and spaces. The presence of caves may influence the design project of repairs or retrofit of upper buildings. Important is also the ownership of the caves and the necessity of preserve them as an historical sign.

For these reasons the possibility to get a part of grant to put in safe and reduce the vulnerability of buildings due to caves was introduced.

Thus the *Allowable Grant* (*AG*) is computed as follows (*m* is the number of buildings in aggregate):

$$AG = \sum_{j=1}^{m} \left[CC_j \cdot \left(1 + \sum_k ib_k \right) \right] \cdot \left(1 + \sum_k ia_k \right) \quad (2)$$

Once *AG* has been computed the final contribution (the so called "payable grant") is obtained by taking into account the following costs: structural and geotechnical tests (GEO-STRU), technical and administrative expenses, VAT.

3. Preliminary analysis on reconstruction costs

By the 30th of April 2016, 660 parametric IMC requests have been accomplished (660 AMU corresponding to 616 BA and 2852 buildings); 292 of these have been approved for a total amount of around 351 million of euro (including professional expenses and taxes), see Fig. 5.

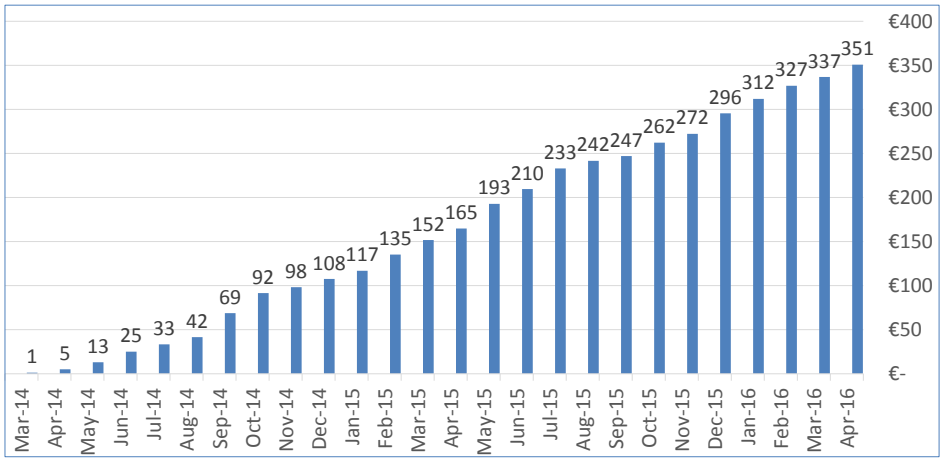
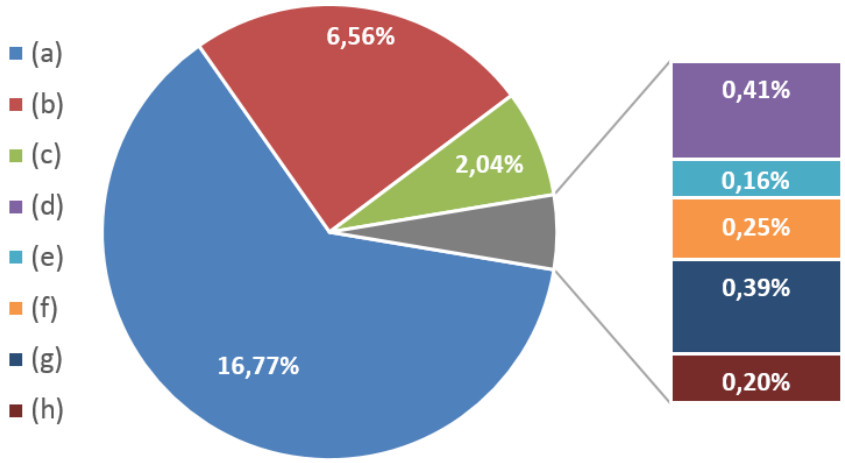


Fig. 5 - IMC requests approved (Mar. 2014 - Apr. 2016, millions of euro)

As for the grant increases for presence of valuable architectural elements and structural complexity, an average increase of 14% of works cost was assessed (see Fig. 6). A relevant category of increase is the site position: around 5,8% of the grant amount has been approved so far; whereas the total amount of requests about shore removing and for ruins reinforcement is found to be not significant so far. The effect of grants increases related to shores removal, underground caves, ancillary urban items and minor elements characterizing the urban image is negligible with respect to the other parameters, so far.



Increase	Allowed grant	Incidence on AG
(a) Valuable elements	€ 41.013.063,38	16,77%
(b) Siting difficulties	€ 16.041.387,64	6,56%
(c) Local amplification	€ 4.980.526,78	2,04%
(d) Shores removal	€ 994.457,85	0,41%
(e) Ruins safety	€ 390.072,00	0,16%
(f) Caves	€ 613.665,39	0,25%
(g) Minor elements	€ 953.774,35	0,39%
(h) Ancillary urban items	€ 500.103,89	0,20%

Fig. 6 - Increases percentage related to total cost of approved interventions

4. Conclusions

This memory describes the main aspects of the parametric procedure of the Integrated Model for the municipalities of the Crater (IMC), used to define the public grant amount to restore private buildings in 56 historical centres close to L'Aquila city, after April 2009 earthquake that hit the Abruzzo Region in Italy.
According to similar methods used after earthquakes and by treasuring the first phase of the Abruzzo reconstruction experience, significant innovations where contrived to reduce the time needed to check the grant requests and, at the same time, to enhance both architectural and structural peculiarities of historical areas hit by the earthquake.
After two years since the introduction of this parametric model, the main achievements reached are the reduction of time to check the grant requests, together with the control of the public expense, even guaranteeing safety and quality in the reconstruction process.

5. Acknowledgements

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