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Measuring the progress of a recovery process after an earthquake: The case of L'aquila, Italy

Diana Contreras[a,*], Giuseppe Forino[b], Thomas Blaschke[c]

[a] Global Earthquake Model (GEM) Foundation, Via Ferrata 1, 27100 Pavia, Italy
[b] University of Newcastle (UON), Newcastle, Australia
[c] Department of Geoinformatics - Z_GIS, University of Salzburg, Schillerstrasse 30, 5020 Salzburg, Austria

A R T I C L E I N F O

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A B S T R A C T

After the earthquake in 2009, L'Aquila (Italy) began a recovery process characterized by a delay in the reconstruction of the city center. Between 2010 and 2014 a recovery index was formulated based on spatial indicators, such as building condition and building use, to measure the progress of the recovery process in L'Aquila. Eight years after the earthquake, the work presented in this paper was used to update the recovery index, not only by measuring the progress of the recovery in L'Aquila but also by validating the usefulness of the proposed recovery index. To achieve this objective, the current research considered the same set of spatial indicators that were used to determine the progress of the recovery in L'Aquila by 2010, 2012, and 2014 in the revaluation of the expert criteria. It was found that in 2016 the number of reconstructed buildings and buildings under ongoing construction had significantly increased and the number of buildings with residential and commercial use had increased along the main roads. While progress was observed in the overall building condition, there was no significant progress in the building use. This poses several questions about how the recovery process can contribute to the return of the inhabitants to the city center of L'Aquila. The paper concludes that the proposed recovery index is useful for identifying the spatial pattern of the recovery process in an urban area affected by an earthquake. At the same time, this recovery index allows the recovery progress to be quantified based on indicators.

1. Introduction

On the 6th of April 2009, an earthquake with a magnitude of 6.3 M_W and a hypocentral depth of 10 km struck the Italian city of L'Aquila (population 72,800). The epicenter was Poggio del Roio, 3.4 km to the southwest of the L'Aquila city center. L'Aquila is the capital of the namesake province and the administrative capital of the Abruzzo region in central Italy. Its location is shown in Fig. 1a and b.

L'Aquila and surrounding areas were badly damaged; 67,500 people were left homeless (2010), 1500 people were injured (202 seriously), and 309 people lost their lives. About 10,000 buildings were damaged, and between 1.5 and 3 million tons of waste were generated [7]. Electricity, gas supplies and telephone lines were reported to have been damaged by the earthquake [24]. The cost of the damage was estimated at 16 billion Euros [43]. Due to the extensive damage, the city center of L'Aquila was cordoned off and declared a restricted zone until 2014, as depicted in Fig. 1c. However, seven years after the earthquake occurred restricted use is still imposed on several buildings and some streets remained closed due to reconstruction works.

According to Alexander [3], the earthquake in L'Aquila "was a moderate seismic event" compared to the magnitudes of other worldwide events, but with a high magnitude for a European country [38]. However, the high physical vulnerability level of L'Aquila's unstrengthened masonry buildings [38] - mainly concentrated in the historical city center - led to the enormous damage described earlier.

To create new living spaces for displaced citizens, two different strategies of relocation were enacted: small settlements, called *Moduli Abitativi Provvisori* (Temporary Housing Prefabs) (MAPs), were established in damaged pre-existing settlements, and large new towns were constructed around L'Aquila in the framework of the *Complessi Anti-Sismici Eco-compatibili* (CASE) Project (Earthquake-proof Eco-compatible Housing Complexes) [11,10]. MAPs covered 54 localities, including 26 sites within L'Aquila boundaries, while the CASE Project included 184 buildings and 5736 residential flats at 19 sites around L'Aquila. 15,000 evacuees were placed in the CASE Project and 8500 people in MAPs; thus, accommodating approximately 23,000 survivors in total.

This housing solution, however, presented problems in terms of lack

* Corresponding author.
E-mail addresses: diana.contreras@globalearthquakemodel.org (D. Contreras), giuseppe.forino@newcastle.edu.au (G. Forino), thomas.blaschke@sbg.ac.at (T. Blaschke).

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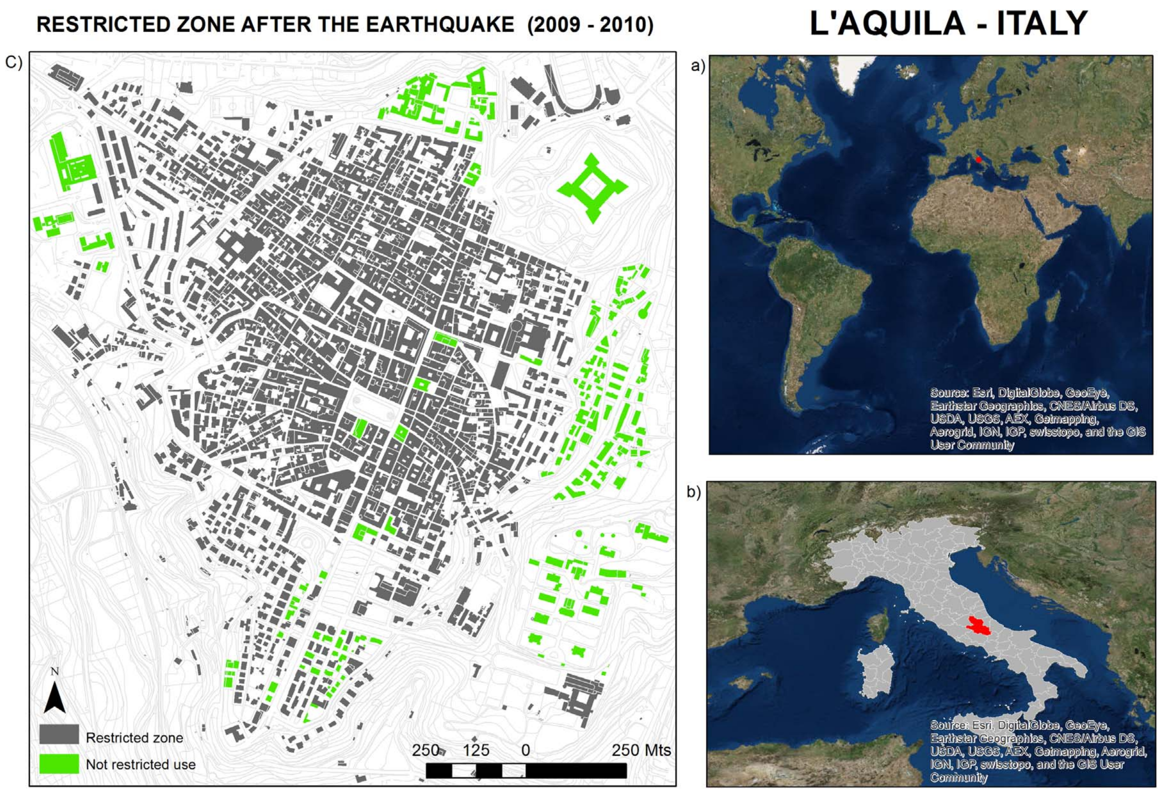


Fig. 1. a and b Location of the case study area: L'Aquila, Italy; c Restricted zone in L'Aquila after the earthquake on 6 April 2009.

of basic services, including sewage, pharmacies, post offices, supermarkets, schools, churches, social and sports centers, (Contreras, Blaschke et al.), and public transport (low and at unreliable frequencies) [18]. This housing solution also did not consider the social or spatial characteristics of L'Aquila and the centuries-old relationships between the historical center and its surrounding neighborhoods [27]. Nowadays, some of these apartments have already been abandoned by their inhabitants because of their size, lack of facilities, and general bad condition, despite the fact that they have only been occupied for eight years [40].

Besides the problem of the lack of urban facilities around the new settlements in L'Aquila, there was also the issue of closing the city center filled with historic buildings, which were most affected by the earthquake [38]. This historic city center used to provide an essential part of the urban economy, which is also important for recovery [4]. After the earthquake, cordoning off the city center was justified with the need to support the damaged buildings using the electro-welded buttress for the safety of the pedestrians and to avoid the harmful effects of construction and demolition (C&D) waste on the population and environment [42]. Several discussions took place within the government on the recovery of L'Aquila, which included the idea of relocating the whole city [5].

Eight years after the earthquake, the city center of L'Aquila still has plenty of ongoing construction works [40]. In the last years, several bars have opened in this area, making the city center a leisure area. The reconstruction and returning processes advanced faster around the historical city center, compared to the 59 outside neighborhoods. According to the Special Office for the Reconstruction in L'Aquila, the reconstruction of the city center will finish in 2023 [40]. It is thus timely and appropriate for this paper to revise and validate the methodology proposed between 2010 and 2014 [16,19] to measure the progress of the recovery in an urban area after an earthquake.

The remainder of the paper is organized into six sections. Section 2 reviews the concept of recovery, the post-disaster phases, the assessment of the recovery based on spatial indicators, and state-of-the-art in the research about the recovery of historic buildings. Section 3 outlines the revised methodology in four parts: fieldwork, sampling area, categories and indicators selected, and expert weighting and hotspots of recovery in the city. Section 4 presents the progress in the building condition and building use and a comparison of the hotspots of recovery in 2010 and 2016. Section 5 discusses changes in weights allocated by experts, considerations by experts for the allocation of weights to some categories, the new aspects of the methodology, the description of the current situation in L'Aquila, and the advantages of having a methodology for measuring recovery. Section 6 concludes by outlining the findings of the fieldwork regarding the allocation of weights by the experts and the new aspects of the methodology.

2. Literature review

Recovery is a "unique time" in which actions can be undertaken to prevent and mitigate the long-term risks caused by natural hazards in the physical, economic, and social dimensions [35]. Recovery goes beyond the reconstruction of buildings and infrastructure, as it implies the rebuilding of people's lives and livelihoods [13]. Rather than a strictly defined phase, it is more context and location specific, defined by the actions of the affected community. Curtis et al. [22] consider recovery as a spatially and temporally dynamic process. According to Blakely and Fisher [6], rebuilding is inherent to recovery, but recovery clearly needs social and cultural rehabilitation. The International Strategy for Disaster Risk Reduction ([29], 23) defines recovery as "the restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors".

In this paper, recovery is conceptually defined as a complex multidimensional long-term process of planning, financing, and decision making after a disaster. The main goal of this process is to restore sustainable living conditions of a community or an area strongly influenced by vulnerable conditions in the physical, social, economic, institutional, cultural, and ecological dimensions that existed before the event. The recovery process must address the interaction between a variety of individuals, groups and institutions with the aim of rebuilding people's lives and livelihoods, as well as reconstructing buildings and infrastructure, and restoring cultural assets and ecological conditions [19].

The recovery reflects the idiosyncrasy of the affected area. More vulnerable areas will have longer recovery phases [31,45] and each recovery case is unique according to the vulnerability conditions existent before a disaster. For example, after the Fukushima earthquake in 2011, Aldrich [2] found that municipalities with the highest levels of trust and interaction within local communities had lower mortality levels. In New Zealand, Christchurch had to close its city center for two years after the earthquake in 2011, and there are still demolition tasks and empty parcels, but the city has managed to advance in its recovery process. The institution in charge of reconstruction located monuments in some of the empty parcels and built symbolic buildings, such as the Cardboard Cathedral (also called the transitional cathedral) and founded the Quake City Museum. A tourist route was designed around the affected area and a temporary shopping mall, called Re-START, was built from shipping containers. Some artists painted murals on the walls of the remaining buildings next to the empty parcels [15].

It is acknowledged that the assessment of the recovery process should be based on indicators to guarantee objectivity and comparability [39]. Indicators are qualitative or quantitative measures resulting from systematically observed facts [34] which describe the characteristics and allow the assessment of certain phenomena [25]. The mathematical combination of a set of indicators forms composite indicators. Another method to measure the progress of the recovery in an urban zone is based on targets. The organization of the recovery process after the earthquake in Kobe (Japan) provides a model to measure the recovery progress based on three targets: 1) rebuild all damaged houses in three years; 2) remove all temporary shelters within five years, and 3) complete the physical recovery in ten years. The Hyogo Prefecture was able to meet these three key targets [6]. The period required by a society to recover from a disaster depends on the magnitude of the event, the level of preparedness, and the economic wealth [37].

After the earthquake in 1995, the city government of Kobe decided to adopt the Plan, Do, Check, Act (PDCA) management strategy to monitor the progress of the awareness of recovery among the citizens when implementing the Kobe City Recovery Plan. Two comprehensive recovery assessments were undertaken in 1999 and 2003. The objective of these assessments was to collect opinions from the citizens. The Kobe City Recovery and Rejuvenation Council proposed to formulate an easy-to-understand index with citizen participation to evaluate the achievements of the “Kobe City Recovery Plan Promotion Program”. The outcome index was named the Citizen-Happiness Index. These indices include 16 prioritized measures and 45 individual indices. Citizens, stakeholders and officials from the government cooperated to select the individual indices. To measure life recovery, 12 workshops were carried out in Kobe to answer two questions: (1) what does life recovery mean to earthquake victims; and (2) which factors do citizens feel are helpful in the promotion of life recovery? The outcome highlighted the seven elements of (1) housing, (2) social ties, (3) community rebuilding, (4) physical and mental health, (5) preparedness, (6) economy, livelihood, and economic and financial situations, and (7) relationship to the government [28].

Furthermore, Brown, Platt and Bevington [8] developed a system to monitor and evaluate the recovery process based on physical, environmental, social and economic factors. Accordingly, duration and quality of recovery can be monitored and evaluated by comparing key indicators to baseline statistics. Brown et al. [8] identify six sectors that need to be considered when evaluating the recovery process, namely, transport, building/shelter, transitional shelters and IDPs, services, environment, and livelihoods. Meanwhile, during the conference on Post-Disaster Needs Assessment (PDNA) in 2008, Brown et al. carried out a survey to identify information and indicators, and gaps in both, used by relief and development agencies to monitor recovery. They found that participants tended to prioritize indicators relevant to their agencies. The top five indicators selected by the user needs survey were, in descending order: livelihoods, crops/livestock/fisheries, water quality, housing reconstruction, drinking water, and road reconstruction.

Contreras [15] compiled a total of 79 indicators of recovery after earthquakes distributed over six dimensions: physical, social, economic, institutional, cultural and ecological. Indicators were organized in a checklist with the recovery phases on the X axis and the indicators on the Y axis. If the action implicit in the indicator is taken during the time in which the evaluation is carried out, it is assigned a value of “1”, otherwise it is assigned “0”, or “−1” if the activity is delayed. This checklist can be used anytime during the recovery process to monitor and evaluate the recovery process.

In 2011, the University of Florence carried out the MICRODIS project, with the aim of studying the epidemiological, social and economic effects of the earthquake that struck L'Aquila. The University of Florence undertook a survey of people relocated to the new settlements in L’Aquila. Respondents were divided into three age groups: elderly (aged 65 or above); adults (between 19 and 64 years) with children; and young people (between 15 and 18 years). Respondents were asked to allocate weights to different facilities according to their relative importance. Elderly allocated the maximum weight to several facilities: bus stops, pharmacies, health facilities, post offices, bars, supermarkets, churches and social centers. Adults assigned the maximum weights to pharmacies, daycare centers, schools and supermarkets, while young people did the same for supermarkets, social and sports centers. The University of Florence also created a site preference index to determine people's desire of moving to a different place from that to which they were relocated [18].

While several indices have been developed to measure vulnerability, only relatively few authors have considered a recovery index [30]. Noteworthy are the works by Shohei [39], Chang [13] and, particularly, Brown et al. [8] who used spatial indicators to measure the recovery progress in Ban Nam Kem (Thailand) after the 2004 Indian Ocean tsunami and in Chella Bandi Muzaffarabad (Pakistan) after the 2005 Kashmir earthquake. Furthermore, Curtis et al. [22] formulated a recovery score to monitor the recovery of the parcels in the Waldo Canyon in Colorado (USA) at two intervals (six months and one year post-event) after a wildfire by using geospatial videos and GIS. This remote sensing method was also applied to monitor the recovery in New Orleans, San Diego, Joplin and Tuscaloosa [21]. Indices are also useful to measure the spatial components of recovery; however, these components have received limited coverage in literature to date. Spatial indicators are evident measurements of the stage reached in the recovery process, making it easier to design a recovery plan during the early stage and to make subsequent evaluations of the progress. According to Platt, Brown and Hughes [37], there are several methods to measure recovery. These methods can be: satellite imagery analysis, ground surveys, and observations, official publications and statistics [20], volunteered geographic information (VGI), social audit (key informant interviews, focus group), households surveys and insurance data.

Monitoring a recovery process contributes to controlling any emerging causal factors of vulnerability, and the reproduction of the pre-existing conditions that may have contributed to the original disaster can thereby be avoided. It also provides data that can be used to assess the resilience of a community, and also encourages the formulation of pre-impact recovery plans (or the improvement of existing recovery plans) for other locations worldwide [20].

3. Methodology

The use of spatial indicators allows a more comprehensive and

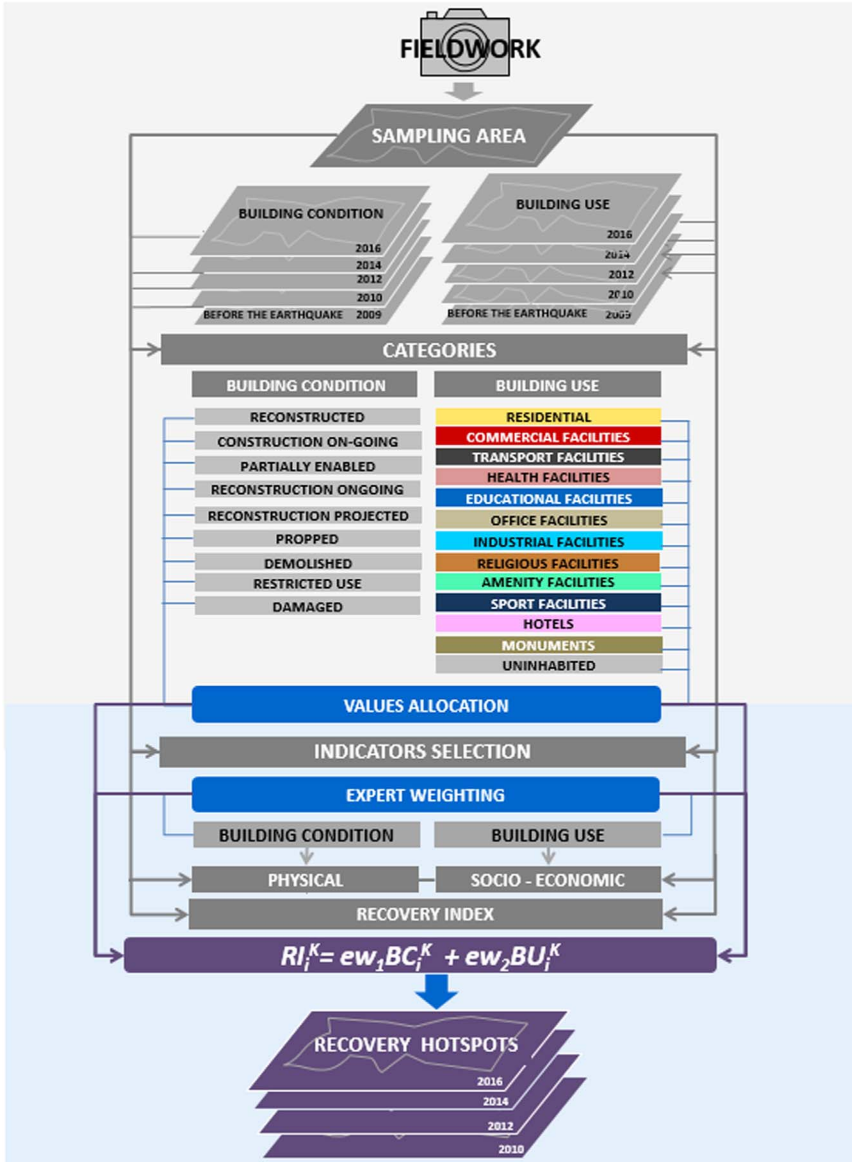


Fig. 2. Revised methodology.

evidence-based assessment of the recovery process. The paper hypothesizes that a) variables related to building conditions and building use after an earthquake can be aggregated to two meta-indicators representing the physical dimension and the socio-economic dimension after an earthquake, respectively, and b) that the spatial distribution of these parameters can constitute an index to assess recovery processes after earthquakes.

The methodology of this research entails five steps: 1) data collection 2) data processing; 3) identification of categories and indicators 4) allocation of weights by experts to each spatial category and indicators to form a recovery index; and 5) determining the hotspots of recovery in L'Aquila. The sequence of the methodology is portrayed in Fig. 2. The building use before the earthquake is based on the observation of the store names and the photographs taken during the fieldwork campaigns, and information extracted from photographs available in *Google maps* and the 3D model of the city of L'Aquila in *Google Earth*.

3.1. Data collection

Two methods of data collection were combined: remote sensing and ground observations. In the case of remote sensing, two methods were used for change detection: visual inspection (also known as manual interpretation) and semi-automated analysis. Visual inspection was carried out by comparing satellite images from before the earthquake (2006) and after the earthquake (2009) to detect any damage to buildings. The image from after the earthquake (2009) was then compared with a satellite image from 2011 to detect any progress in the recovery process. This search for changes and damages was also supported by Google Earth, the damage indication maps produced by Tiede [41], the local magazine *Noi Abruzzo* - edited by the commission of reconstruction of L'Aquila and disseminating information about the projects, laws with respect to the recovery, plans, programs, and the progress of the reconstruction in L'Aquila - and the damage degree map retrieved from Contreras et al. [19] which also incorporates relevant information from the mentioned sources.

QuickBird imagery was used in this research. The second method for change detection in buildings was designated as a semiautomatic analysis due to the integration of expert knowledge into the decision rule set to assist in the change detection and refine the results and tailor the method to the specific data available. To detect changes in L'Aquila during the early recovery and recovery stages, an additional *QuickBird* image from 2011 was acquired.

Change detection analysis following an earthquake identifies changes in the ground/earth surface and in man-made structures such as buildings, irrespective of whether the changes reflect damage due to the earthquake or result from reconstruction or demolition. The applied change detection approach was based on an initial classification of the 2011 image and a comparison of the resulting classes (and objects) with the spectral information from the 2009 image, within an integrated environment. The main features used to distinguish changes in buildings between 2009 and 2011 were: spectral, textural and geometric features [20].

Ground observations (GO) were made during the field visits to L'Aquila. Four field visits were made to L'Aquila in 2010, 2012 [19], 2014, and 2016 [15]; that is one, three, five and seven years after the earthquake. The main activities during the field visits involved (1) visiting the former restricted zone and its surroundings; (2) visiting the new settlements around L'Aquila; (3) the collection of cadastral data and aerial photographs of L'Aquila; and (4) interviews with members of the Department of Civil Protection in 2010, and members of the Settore Ricostruzione Pubblica—Ufficio Progettazione (Office of Public Reconstruction—Office of Planning) in 2014. A monitoring schedule, including details of the tools used to collect the data, was an essential part of the research. This schedule was formulated at the start of the study but subsequently adjusted according to the availability of the means, resources, and data required for the research [15]. This monitoring schedule is outlined in Table 1.

We gained experience in collecting data through ground observation. This can also be applied to monitor the recovery process in other Historical Centers (HC) to differentiate between the damage and lack of maintenance in buildings and to determine when a building is uninhabited or not. The use of satellite images enabled us to differentiate between true positive and false positive changes, which result from differences in the angle and illumination in the image. This last tool illustrated the importance of the validation of the changes detected in the satellite images by the ground observation because not all detected changes reflected progress in the recovery process. Some changes were the product of the deterioration of the buildings damaged by the earthquake over time [20].

In 2010, the city waste contractor ASM estimated that the waste management process would be completed in two years [42]. However, in the April 2014 fieldwork, machines and trucks were still observed removing rubble in parts of L'Aquila. In 2016, the remaining debris mainly stemmed from the reconstruction works, but damaged buildings that still needed to be cleared of debris remained.

In 2016, newly reconstructed buildings could be observed in L'Aquila (see Fig. 3a and b). Buildings that had been classified as being in reconstruction projected over six years were finally in reconstruction ongoing (see Fig. 3c and d). Meanwhile, other buildings remained propped (see Fig. 3e and f) or were still awaiting a decision (damaged) (see Fig. 3g and h). The changes in the buildings' conditions between 2010 and 2016 are illustrated in Fig. 3.

The condition of the buildings affected by the earthquake can be: waiting for a decision (damaged), restricted use, demolished, propped, reconstruction projected, reconstruction ongoing, partially enabled, construction ongoing or reconstructed. Determining whether a house was occupied or not during the fieldwork campaigns sometimes proved challenging due to the oftentimes remaining presence of curtains and household goods in uninhabited dwellings. Furthermore, it was sometimes difficult to distinguish between a lack of maintenance and the damages produced by the earthquake, which also caused difficulty in determining whether the house is inhabited or abandoned. Between 2010 and 2016, it was possible to observe several buildings reconstructed and inhabited, particularly houses around the historical city center.

3.2. Data process

The sampling area is the historical center of L'Aquila as a district and node [32], limited by the main roads. The sampling zone was selected for several reasons: it was the most affected area after the earthquake and the one in which the greatest number of deaths was reported. Additionally, there was an existing damage indication map of this zone elaborated by Tiede [41].

3.3. Identification of categories and selection of indicators

The fieldwork campaigns allowed us to determine the categories that make up the indicators for the recovery progress of L'Aquila. During fieldwork, nine categories of buildings were classified based on their condition, namely: *damaged, restricted use, demolished, propped, reconstruction projected, reconstruction ongoing, partially enabled, construction ongoing, reconstructed*. The category *partially enabled* refers to propped buildings in which the ground floor was occupied by, for example, stores, bars, or restaurants, while the other floors remained empty, awaiting reconstruction.

These categories were considered variables of the indicator *building condition*, belonging to the physical dimension of the recovery. In this step of the methodology, thirteen categories of building use were also identified, namely: *uninhabited, monuments, hotels, sports facilities, amenity facilities, religious facilities, industrial facilities, office facilities, educational facilities, health facilities, transport facilities, commercial facilities*

Table 1
Monitoring schedule of the post-disaster recovery progress in L'Aquila, Italy.

Timeline		Remote Sensing (RS)			Ground Observations (GO)		Geographic Information System (GIS)
N[a]	Year	Month	Sensor	Analysis	Month	Tools	Software/applications
1	2010				April	GPS Analogue maps interviews	Arc GIS 9.3–10 Google Earth Google Maps
	2011	September	Quickbird	OBIA GIS			
3	2012				September	GPS Analogue maps	Arc GIS 10.1 Google Earth Google Maps
5	2014				April	GPS Analogue maps interviews	Arc GIS 10.3 Google Earth Google Maps
7	2016			OBIA	July	GPS	Arc GIS 10.4
14	2023[b]	April	Quickbird	GIS	April	Analogue maps interviews	Google Earth Google Maps

[a] Number of years after the earthquake.
[b] Fieldwork planned.

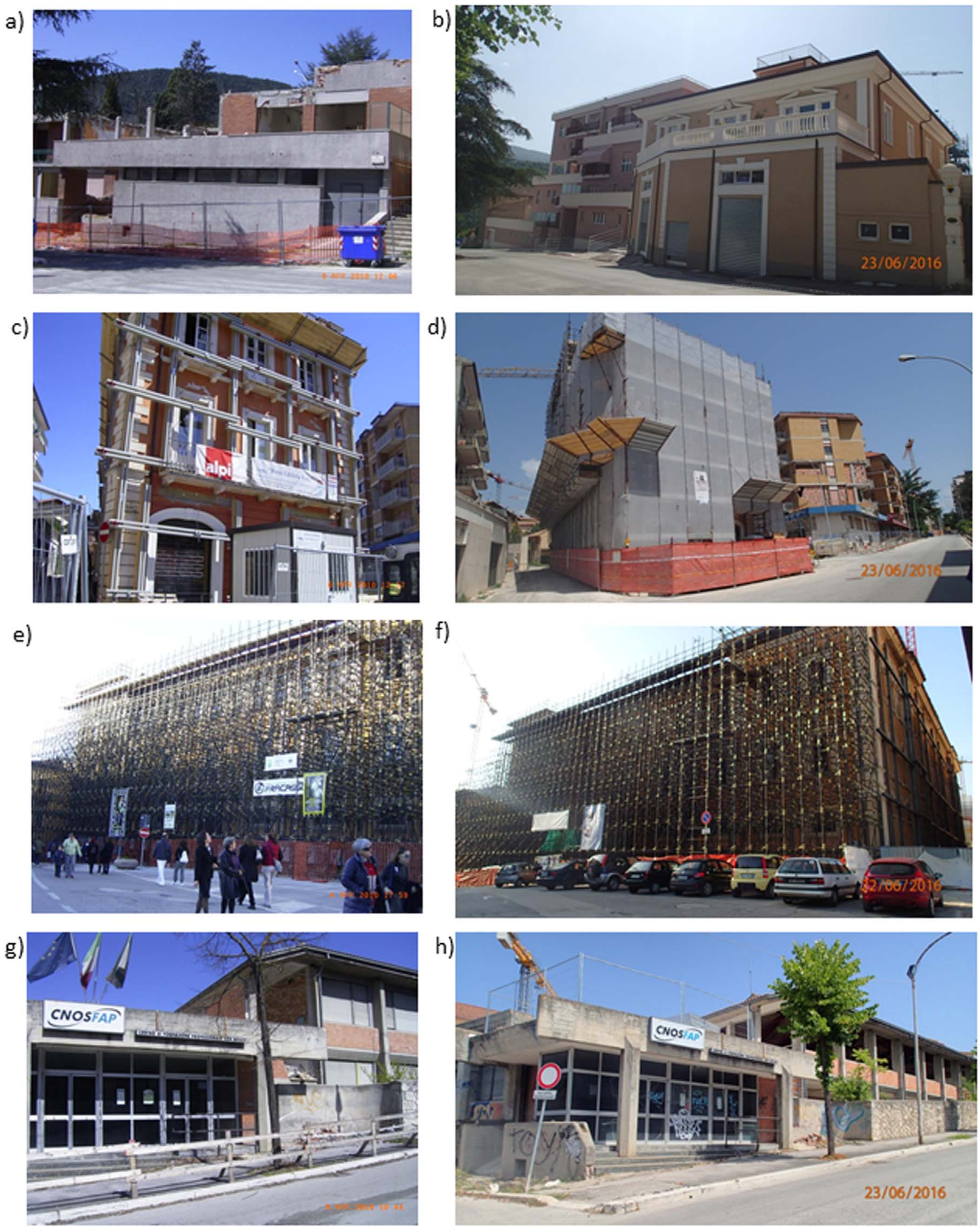


Fig. 3. Changes in L'Aquila (Italy) between 2010 and 2016. A) House located in front of the cross between the streets Strada Statale 17 and Via XXIV Maggio (2010); b) House located in front of the cross between the streets Strada Statale 17 and Via XXIV Maggio (2016); c) Building located over the Via XX Settembre between Via Orto Agrario and via delle Bone Novelle (2016); d) Building located over the Via XX Settembre between Via Orto Agrario and via delle Bone Novelle (2010);e) Building located between Via S. Bernardino and Piazza del Teatro and between Via S. Giovanni da Capestrano and Via S. Giacomo della Marca (2010); f) Building located between Via S. Bernardino and Piazza del Teatro and between Via S. Giovanni da Capestrano and Via S. Giacomo della Marca (2016); g) Center of Professional Training "Don Bosco" (2010) and h) Center of Professional Training "Don Bosco" (2016). Photos by Diana M. Contreras M.

and residential.

These categories were considered variables of the indicator *building use*, belonging to the socio-economic dimension of the recovery. Both indicators *building condition* and *building use* are aggregated into a *recovery index*.

Through observations during the fieldwork, it was possible to map and subsequently quantify the changes in the building's conditions between these seven years. The changes in the building use between 2009 (before the earthquake), 2010 2012, 2014 and 2016 were derived from the combination of primary and secondary data. To deduce the building use before 2009, secondary data were extracted from tourist maps of the city center of L'Aquila drawn before the earthquake, and from Google Maps and Google Earth 3D-buildings. Especially in Google Earth, it is still possible to observe the condition of some streets in

L'Aquila prior to the earthquake. Looking at the observed announcements above some doors in the pictures posted on Google Earth-3D building and validated during fieldwork, it was possible to infer what the use of buildings was before the event. The data of the building use in 2010, 2012, 2014 and 2016 in the city center of L'Aquila was obtained as primary data during fieldwork, through the observation of the activities going on in the streets and mapping the location of the places in which they occur.

It was assumed that all the buildings were occupied at the HC at the moment of the earthquake. We only consider the use of a building if it is inhabited or occupied, else we consider it *uninhabited*. We consider partial occupancy in the category *partially enabled* in the building condition indicator.

Alexander [4] stated that sources of work and income are essential for the recovery process. Many buildings along the streets Corso Federico II, Corso Vittorio Emanuele, Via Garibaldi and Via Fontesecco were already inhabited on the first floor by 2012, while their other floors remained empty. These buildings host facilities such as restaurants, bars, cafes, banks, hotels, and offices, which have increased in number between 2010 and 2016, but with some drop in 2014 due to reconstruction works. Some of the facilities are located in the same place as they had been before the earthquake.

3.4. Weights allocation

After having quantified the changes observed in the buildings within the land restriction area between 2010, 2012, 2014, and 2016, and the changes in building use between 2009 (before the earthquake), 2010, 2012, 2014, and 2016, expert weighting was used to determine which categories of building condition and building use contribute most to the progress of the recovery process after an earthquake. The scales of values for the weighting process are presented in Table 2.

In weighting the indicator categories, the experts considered the evidence from the MICRODIS project [44], as well as the surveys carried out in Kobe to determine what life recovery means to earthquake victims and what factors the citizens consider helpful to the promotion of life recovery [28]. In the initial approach of the methodology in 2014, the weights were allocated by three experts with geography and disaster management background. For the revision of the methodology in 2016, we involved experts from other disciplines in order to consider different perspectives. In this instance, the group of experts consists of scientists with knowledge of the case study area or experience in monitoring recovery processes. All of them have a track record of publications about recovery in L'Aquila. The experts' backgrounds varied across a range of disciplines, including disaster studies, anthropology, geography, and engineering. The degree of significance allocated to each category of the indicators *building condition* and *building use* is detailed in Table 3 and depicted in Fig. 4.

As in the first version of the methodology [19] and the literature review, the experts considered the category *residential* as the strongest contributor to the recovery process, followed by the category *reconstructed,* and *educational facilities*. Contrarily, *damaged*, *restricted use,* and *uninhabited* were perceived as the categories that contribute less to the progress of the recovery after an earthquake. The result of the weightings for all considered variables is portrayed in Fig. 4.

Table 2
Scale of values of the contribution of each category to the recovery process.

Value	Meaning
10	Excellent/ideal contribution to recovery
9	Very high contribution to recovery
8	High contribution to recovery
7	Important contribution to recovery
6	Good contribution to recovery
5	Middle contribution to recovery
4	Contributes to recovery
3	Somehow contributes to recovery
2	low contribution to recovery
1	Very low Contribution to recovery
0	No contribution to recovery at all

3.5. Hotspots of recovery in L'Aquila

Experts assigned weights to each category of the building condition and building use. The weight is allocated according to what experts consider to be the contribution of each variable to the progress of the recovery. Therefore, every building in the sampling area receives two values according to the weights allocated by the experts: one value regarding its condition in 2010, 2012, 2014, and 2016, respectively; and the other regarding its use classification in the same years. These values are summed up to determine a final recovery score for each building and to come up with the hotspots of the recovery in L'Aquila by every year.

$$RS_i = ew_1 BC_i^K + ew_2 BU_i^K \tag{1}$$

Where

ew_1 = Expert Weight given to the category – building condition
ew_2 = Expert Weight given to the category – building use
i = index of the building
k = year
BC = Building Condition
BU = Building Use
RS_i = Recovery score for building

4. Results

The sampling area of the historic center of L'Aquila included 753 buildings. It was found that the percentage of buildings that were classified as *partially enabled* has decreased by over 4% (29) to 1% (11) between 2010 and 2016. The percentage of buildings *reconstructed* increased from just 5% (41) in 2010 to over 20% (150) in 2016. The percentage of buildings with *reconstruction projected* (announced on a billboard) rose from 2% (13) in 2012 to 4% (29%) in 2014 but slightly fell to 3% (24) in 2016. The percentage of *propped* buildings (still requiring structural support) increased significantly from just 4% (31) in 2010 to over 29% (220) in 2012. However, the percentage of *propped* buildings dropped by over 22% (165) in 2014 and to 16% (121) in 2016. The percentage of *inhabited* buildings reached a record of 15% (110) in 2012, from 13% (99) in 2010; but afterwards, the percentage of *inhabited* buildings continued to decrease from 9% (65) in 2014 to 8% (62) in 2016. The percentage of buildings with *restricted use* (uninhabited) steadily decreased from 82% (621) in 2010 to 44% (332) in 2012, to 9% (67) in 2014 and to 7% (52) in 2016, which is another sign of progress in the recovery process. The percentage of buildings *demolished* reached 3% (24) in 2014, from just over 1% (8) in 2012, but this number decreased again to 2% (18) in 2016. The percentage of *damaged* buildings in the sampling area in the city center of L'Aquila remained high at 23% (174) in 2014 [14] and decreased slightly to 20% (152) in 2016. These results are plotted in Table 4 and Figs. 5 and 6.

Using the same sampling area and sampling size (743 buildings) to monitor the building condition from 2010 to 2016, it was found that the percentage of *uninhabited* buildings in the formerly restricted zone has been slightly decreasing since 2010 when 86% (648) of the buildings included in this sampling were not inhabited. By 2012, the percentage of *uninhabited* buildings had decreased slightly to 81% (611), and to 75% (568) in 2014 where it remained at 75% (561) in 2016. Between 2012 and 2014, there was limited progress in the number of recreation facilities available (3), representing a 20% increase from the number of *amenities* available in 2009. There was no progress in this kind of building use by 2016. There was an increase of 77% (34) in the number

Table 3
Expert values and weights allocated to variables of the indicators: building condition and building use.

D	IND	CATEGORIES	VALUES EXPERTS								AV	Nw
			1	2	3	4	5	6	7	8		
FISICA	**BUILDING CONDITION**	Reconstructed	10	9	8	9	7	7	3	10	8	0.07
		Construction ongoing	9	9	6	7	6	5	2	8	7	0.06
		Partially enabled	6	6	6	8	3	5	1	9	6	0.05
		Reconstruction ongoing	7	8	5	7	6	6	3	8	6	0.06
		Reconstruction projected	4	7	2	5	5	7	1	7	5	0.04
		Propped	0	3	0	1	3	3	0	8	2	0.02
		Demolished	3	6	2	4	6	4	0	0	3	0.03
		Restricted use	0	5	0	1	2	0	0	1	1	0.01
		Waiting for decision (damaged)	0	5	0	2	1	0	0	0	1	0.01
SOCIO - ECONOMIC	**BUILDING USE**	Residential	10	8	9	10	8	9	3	10	8	0.08
		Commercial facilities	9	7	9	8	1	8	3	9	7	0.06
		Transport facilities	8	4	4	8	2	9	3	9	6	0.05
		Health facilities	7	5	8	9	3	8	3	9	7	0.06
		Educational facilities	6	6	9	9	5	10	3	9	7	0.07
		Office facilities	6	6	7	8	6	8	3	7	6	0.06
		Industrial facilities	6	5	7	9	1	4	3	3	5	0.04
		Religious facilites	2	5	8	5	6	6	3	4	5	0.04
		Amenity facilities	4	5	8	7	4	6	3	5	5	0.05
		Sport facilities	5	5	7	7	5	9	3	2	5	0.05
		Hotels	6	4	3	5	6	6	2	2	4	0.04
		Monuments	3	5	8	6	1	6	2	2	4	0.04
		Uninhabited	0	3	4	1	2	0	2	0	2	0.01
										TOTAL	110	1

D Dimension.
IND Indicator.
Av Average of values allocated by experts.
Nw Normalization of average values allocated by experts.

of *commercial facilities* available in the sampling zone (44 before the earthquake) in 2014 compared to 2009. There was no increase in the number of *commercial facilities* in 2016. There has been no increase in the number of *educational facilities* (5 before the earthquake), monuments (2 before the earthquake), and *transport facilities* (8 before the earthquake) between 2010 and 2016. There were no longer any *health* (2 before the earthquake) or *industrial facilities* (1 before the earthquake) in the sampling zone in 2016. The number of available *hotels* (4), *offices* (21), and *religious facilities* (8) increased steadily from 2012 to 2014: at 33% (12 *hotels* before the earthquake), 38% (55 *offices* before the earthquake), and 28% (29 *religious facilities* before the earthquake). There was an increase of 1% (22) in the number of *office facilities* available in the sampling zone in 2016 compared to 2014. There was no increase in the number of *hotels* or *religious facilities* available by 2016. The number of *residential buildings* (580 before the earthquake) has been steadily increasing from 76 (10% of the buildings in the sampling zone) in 2010, to 79 (10%) in 2012, to 106 (14%) in 2014 and 113 (15%) in 2016. These results are depicted in Table 5 and Figs. 7 and 8.

After applying Eq. (1) to process the data collected during fieldwork

Fig. 4. Results of experts weighting allocation process.

Table 4
Changes in the building condition in the city center of L'Aquila (Italy) between 2010 and 2016 after the earthquake.

BUILDING CONDITION	2010		2012		2014		2016		Progress	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Reconstructed	0	0%	0	0%	64	12%	163	22%	99	9%
Construction on-going	2	0%	0	0%	0	0%	0	0%	0	0%
Partially enabled	0	0%	29	4%	20	4%	11	1%	-9[a]	-2%[a]
Reconstruction on-going	0	0%	41	5%	145	28%	150	20%	104	23%
Reconstruction projected	0	0%	13	2%	29	6%	24	3%	16	4%
Propped	31	4%	220	29%	165	32%	121	16%	-55[a]	-7%[a]
Demolished	0	0%	8	1%	24	5%	18	2%	16	4%
Restricted use	621	82%	332	44%	67	13%	52	7%	-265[b]	-35%[b]
Damaged	99	13%	110	15%	239[c]	32%	214	28%	129	17%
Total	753	100%	753	100%	514	132%	753	100%		

[a] When there is no progress between 2014 and 2016 in a particular variable, negative values are obtained in the estimation of the progress.
[b] In the case of the variable: restricted use, the reduction in the number of buildings classified under this condition means progress in the recovery process.
[c] The increase in the number of damaged buildings in 2014 is due to the elimination of the restricted zone, and the possibility to assess all the buildings in the sampling zone.

in 2010 and 2016, plus the weighing criteria from the experts, it is possible to map the hotspots of recovery in L'Aquila in 2010 and 2016 and see its evolution as it is plotted in Fig. 9(a) and (b), respectively.

5. Discussion

The categories of building use and building condition considered in the present methodology were revised after each field visit. It was noted that the restricted zone decreased over time from 2010 to 2012, and from 2014 to 2016. Only the entrance to some streets and buildings were restricted in the last two visits either due to reconstruction works or due to the damaged condition of some buildings. The access to the restricted zone and the progress in the reconstruction allowed us to identify new categories of building condition and building use on each visit that were then included in the revised version of the present methodology to measure the progress of a recovery after an earthquake.

The building condition allowed to measure the progress of the recovery process in the physical dimension, as it is usually evaluated. Nevertheless, the aim of the present methodology goes beyond this dimension. Therefore, the indicator building use was developed as a proxy to understand the socio-economic situation at the local level. This is the main reason to monitor the changes in the building use such as *commercial, transport, office, industrial, amenity and hotels*. These facilities are important as they are both sources of services, which contribute to the functionality of the city, and of employment.

For the revision of the methodology, weights were allocated by eight experts - five more than in the first version [19]. This reduces the room for biases since the weights are allocated by more scientists with different backgrounds and experiences related to the recovery process. Some of the experts have also monitored the recovery of L'Aquila from different perspectives or monitored recovery processes after earthquakes in other cities.

During the validation of the methodology, we renamed what we initially called variables as categories, because a building can only be classified under one category and it only receives a numerical value after the weighting from the experts. The category *inhabited* was removed from the spatial indicator *building condition* because it does not describe a physical condition of the building.

One of the experts allocated more weight to the category *demolished* than to *propped* or *restricted use* because, according to him/her, demolition could be the pre-condition for a quick rebuilding process, while a building that is "propped" may remain in such condition for an indefinite time.

Another expert considered that if being propped is part of the

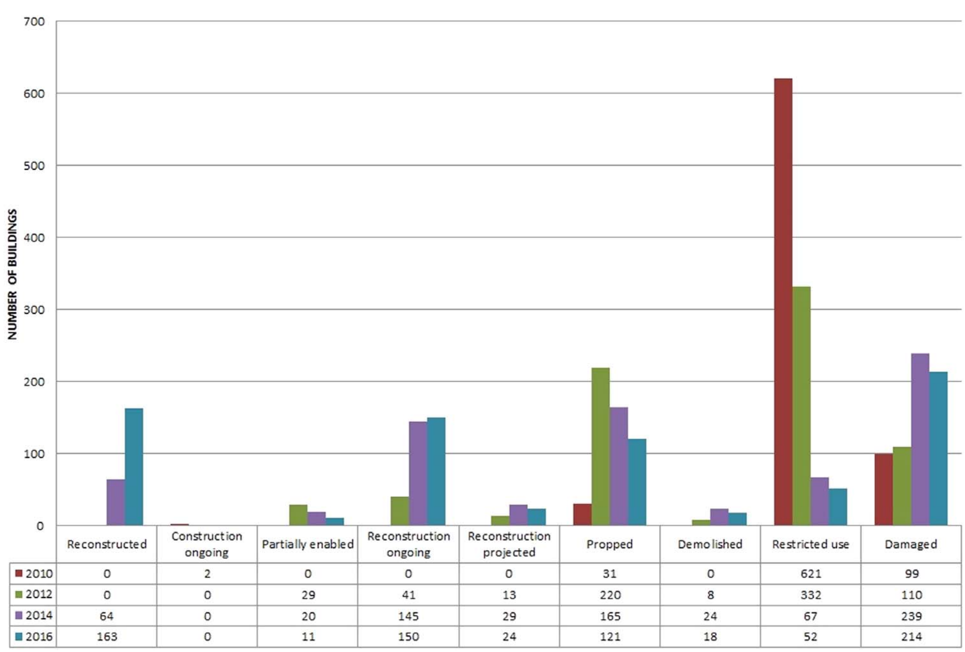


Fig. 5. Comparison of the changes in the building condition in L'Aquila after the earthquake between 2010 and 2016.

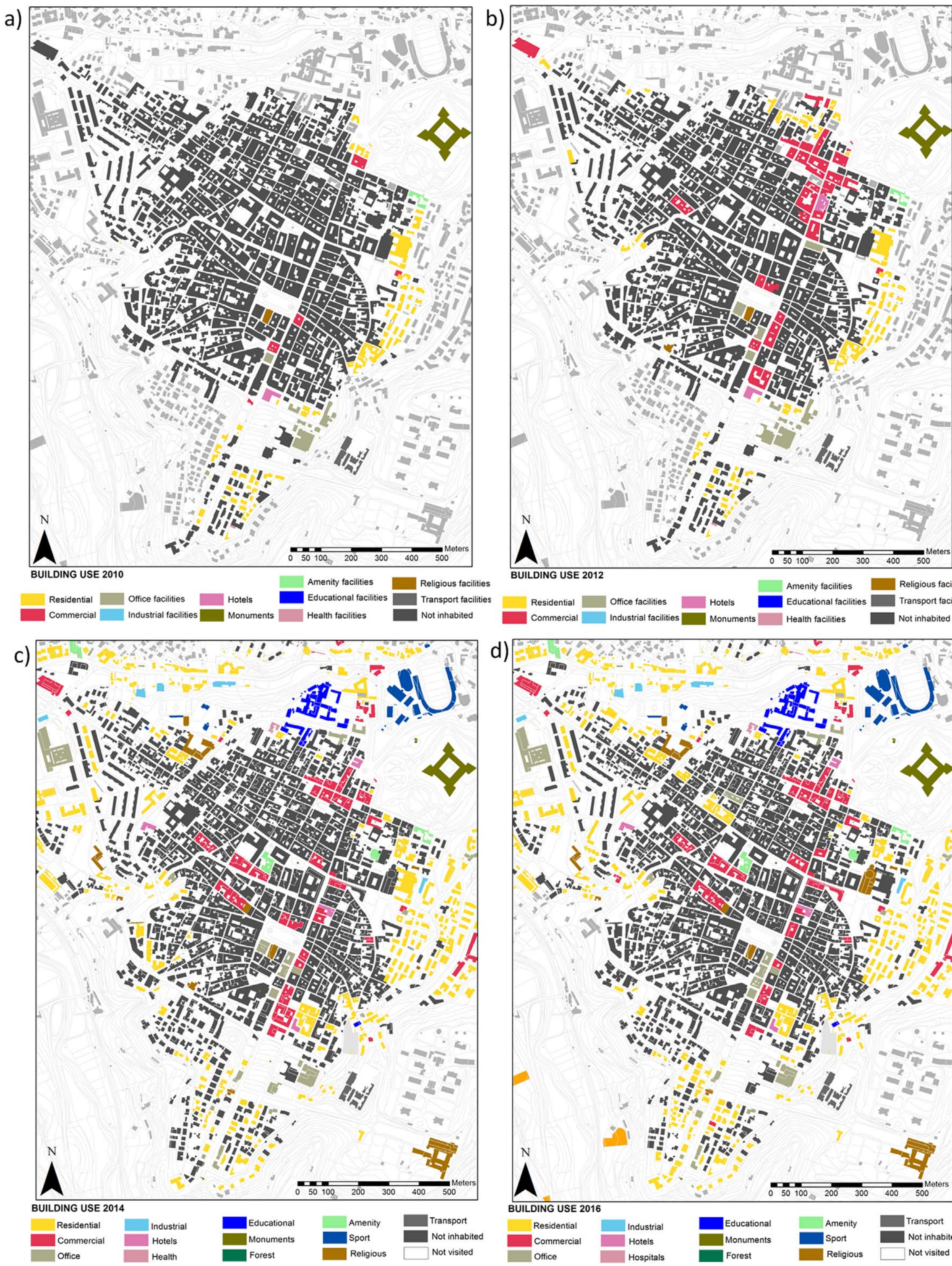


Fig. 6. Building condition in L'Aquila after the earthquake in a) 2010, b) 2012, c) 2014 and d) 2016.

reconstruction process, then he/she would assign the same weight as the reconstruction ongoing, but if it is propped only for supporting purposes with no signs of rebuilding, he/she would assign a lower weight (e.g. 1). If the building is demolished and planned to be rebuilt (in a better condition), he/she would assign a high value (e.g. 7), but if it is demolished and never rebuilt, he/she would assign 0.

Similarly, the expert found some overlap between the categories *restricted use* and *(re)construction ongoing*. In this case, it is necessary to explain that each building classified under the category of *reconstruction ongoing* has a restricted use due to the works that are taking place inside. This is not the case the other way around, the category restricted use is a category of building use that could correspond to several categories of building condition such as *reconstruction projected*, *propped* and waiting for a decision (*damaged*). Regarding the building use, the same expert noted that the weights allocated to the buildings are very place specific. In the specific case of hotels, if the tourism sector constitutes an important economic activity in the city, then the (re)construction of the hotels will be essential for the overall recovery of the city; therefore, the weight allocated must be high. In other cases, the weight allocated to this specific building use will be between middle and low.

This version of the methodology facilitates the estimation of the contribution of each category of building condition and building use to the recovery index. This time, the experts were asked to allocate weights only to the categories and not to the indicators: *building condition* and *building use*, as it was the case in the first version of the methodology. We consider the weights allocated to the variables to be representative enough.

Usually, the physical recovery advances faster, or are at least more evident, than the recovery of the living and the economic conditions. In L'Aquila, houses were quickly built-up outside of the historical city center (OHC) to solve the problem of the homeless, however, totally isolating of the source of employment, the academic centers and the amenities of the city [17]. However, according to Honjo [28] in the workshops conducted in Kobe, the first element that citizens consider helpful to promote the recovery was housing whereas the economy ranked sixth. Wu and Lindell [46] claimed that the damages in the houses substantially affect the lives of the victims; hence, the recovery time of housing is a significant indicator of community recovery [1]. In the case of Mexico City, where an earthquake in 1985 also affected mainly the historical center, the government was criticized for giving priority to recovering economic services and activities, instead of housing like in L'Aquila [23].

In L'Aquila, one source of employment is the construction and demolition industry [4,7]. This industry attracts workers who have been encouraging the opening or reopening of economic activities. However, to be able to discover gradual changes in L'Aquila, it is necessary to go beyond the physical appearance of the facades of the buildings, and to study the socio-economic dynamics taking place in space and time, which can be indicated, for instance, by building use changes.

6. Conclusions

The several fieldworks conducted in L'Aquila suggest that the weights allocated to some categories by the experts must be reconsidered and new categories, especially building use, should be included. These fieldworks also permitted the authors to accumulate more experience and knowledge in measuring the progress of the recovery. One example of the first case is the category of *reconstruction projected*, which does not necessarily mean that reconstruction work will start soon. This category is considered it in the second fieldwork. We had a similar experience with the category *propped*. The category *sports facilities* was added to the indicator *building use* after the third fieldwork visit [15].

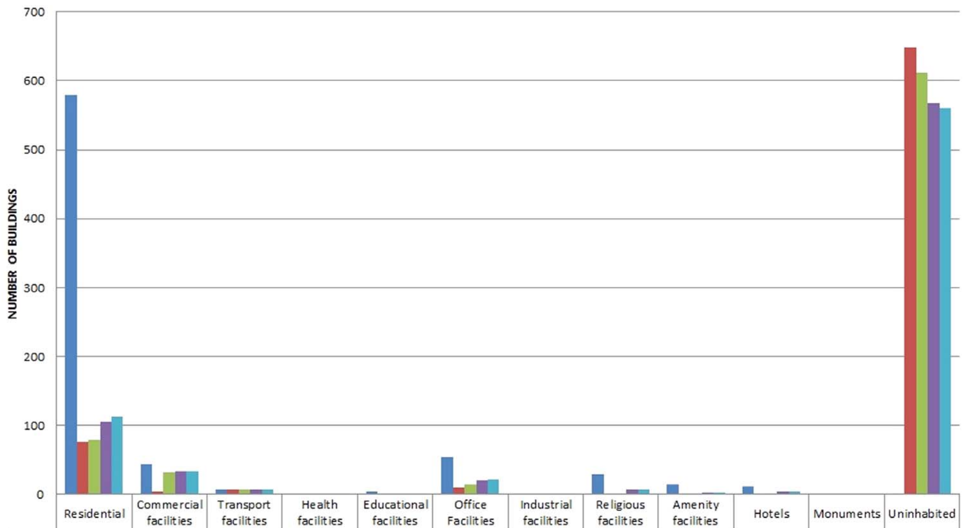
The results of the expert weighting reveal that socio-economic categories aggregated to the indicator *building use* and physical categories aggregated to the indicator *building conditions* were considered equally important for the recovery, which is a very different result from the experts' weights allocation carried out in the first version of the methodology. This can be explained by the different backgrounds of the experts summoned this time, whose expertise on recovery is higher than in the first instance.

Some damaged and propped buildings in L'Aquila have remained at the same stage for seven years because no owner or authority has made any decision yet regarding their future. The reason could be related to property rights. This uncertainty has delayed the recovery of the city center because grants for repair or reconstruction are only allocated to the official owner. Some propped buildings were partially enabled, with some stores opened on the ground floor, while the above floors remained empty between 2010 and 2014. In 2016, we found that these buildings started to be reconstructed instead of being repaired, which represents a somewhat ambiguous step in the recovery process because it constitutes an advance in building condition, but a setback regarding building use. A similar scenario occurred with buildings that were

Table 5
Changes in the building use in the city center of L'Aquila (Italy) between 2009 and 2016.

Building use	Changes										Progres							
	2009		2010		2012		2014		2016		2010		2012		2014		2016	
	Number	Percent-age	Number	Percent-age	Number	Percent-age	Number	Percentage	Number	Percentage	Number	Percen-tage	Number	Percen-tage	Number	Percen-tage	Number	Perce-ntage
Residential	580	2000%	76	10%	79	10%	106	14%	113	15%	−504	13%	3	14%	27	18%	7	1%
Commercial facilities	44	152%	5	1%	33	4%	34	5%	34	5%	−39	11%	28	75%	1	77%	0	0%
Transport facilities	8	28%	8	1%	8	1%	8	1%	8	1%	0	100%	0	100%	0	100%	0	0%
Health facilities	2	7%	1	0%	1	0%	0	0%	0	0%	−1	50%	0	50%	−1	0%	0	0%
Educational facilities	5	17%	0	0%	0	0%	0	0%	0	0%	−5	0%	0	0%	0	0%	0	0%
Office Facilities	55	190%	11	1%	15	2%	21	3%	22	3%	−44	20%	4	27%	6	38%	1	2%
Industrial facilities	1	3%	0	0%	0	0%	0	0%	0	0%	−1	0%	0	0%	0	0%	0	0%
Religious facilities	29	100%	1	0%	2	0%	8	1%	8	1%	−28	3%	1	7%	6	28%	0	0%
Amenity facilities	15	52%	1	0%	1	0%	3	0%	3	0%	−14	7%	0	7%	2	20%	0	0%
Hotels	12	41%	1	0%	2	0%	4	1%	4	1%	−11	8%	1	17%	2	33%	0	0%
Monuments	2	7%	1	0%	1	0%	1	0%	0	0%	−1	50%	0	50%	0	50%	−1	−50%
Uninhabited	0	0%	648	86%	611	81%	568	75%	561	75%	648	0%	−37	6%[a]	−43	7%[a]	−7	0%
Total	29	100%	753	0.86055-78	753	81%	753	75%	753	100%								

[a] It is taken for granted that all the buildings were inhabited in the sampling area in 2009, before the earthquake; hence the estimation of the progress is different, because it is associated with the reduction of the number of parcels not used. The percentage of progress is the difference between the calculated percentage and 100.



	Residential	Commercial facilities	Transport facilities	Health facilities	Educational facilities	Office Facilities	Industrial facilities	Religious facilities	Amenity facilities	Hotels	Monuments	Uninhabited
2009	580	44	8	2	5	55	1	29	15	12	2	0
2010	76	5	8	1	0	11	0	1	1	1	1	648
2012	79	33	8	1	0	15	0	2	1	2	1	611
2014	106	34	8	0	0	21	0	8	3	4	1	568
2016	113	34	8	0	0	22	0	8	3	4	0	561

Fig. 7. Comparison of the changes in the building use in L'Aquila after the earthquake between 2010 and 2016.

found inhabited in the past fieldwork visits and are now in restoration. Transitions in building condition in L'Aquila between 2009 and 2016 are depicted in Fig. 10 and they are similar to the limit state event tree to assess building-level recovery developed by [9].

We found that the number of reconstructed buildings and buildings with ongoing construction, and the number of inhabited buildings has significantly increased since the last fieldwork visit in 2014. The number of buildings classified as partially enabled, propped, reconstruction projected and damaged had greatly decreased by 2016, while the number of demolished buildings and buildings with restricted use slightly increased. The number of buildings with residential and commercial use increased along the main roads by 2016. The higher speed in rehabilitation of recreational and commercial facilities can have several reasons. On the one hand, these facilities were installed mainly in the partially enabled buildings along the main commercial axes: Corso Federico II, Corso Vittorio Emanuele and Via San Bernardino. These axes were the only ones opened between 2010 and 2012 when the HC was mainly cordoned off. These facilities do not require additional infrastructure, and they are needed by the high number of construction workers and by inhabitants of the HC. Moreover, the HC, as in every city center, constitutes a hub where the restaurants and bars are located for the leisure of locals and they are important to reactivate the local economy.

On the other hand, motivations for traders are different to those for residents. Residents must be living in the HC 24/7 and thus suffer the burden of all the inconveniences of living in an area with a disconnected physical and social environment, a fragmented transport network with very limited parking and absent public transport, as well as a number of open construction sites and work in progress which affect mobility, leisure, basic services access (they may restrict water or electricity provision due to maintenance work, for example), as well as health issues (dust, noise). Conversely, traders usually come to the area solely for work, while they also face the inconveniences these are limited to the daytime and working days.

Paradoxically, while progress was observed in the overall building condition, there was no considerable progress in the building use because several reconstructed buildings are still *uninhabited*. This poses several questions about the dynamics of the returning process of the former habitants of the city center in L'Aquila. This returning process will be interesting for further research. The reconstruction and returning process advances faster outside OHC [16]. According to Mannella et al. [33] the trend of population returning home from December 2010–2015 mainly depended on the progress of the reconstruction process. The priority was allocated to the buildings located OHC, to later address the complexity of the reconstruction inside the HC.

Other reasons that could have be considered in the allocation of priority to the neighborhoods OHC, was the need to also reconstruct collaboration networks among the community [17,27]. Coming back to live in a social environment, where people can build relationships or simply buy food for the day.

During the fieldwork, the gas supplies and road networks appeared to be the aspects of infrastructure worst affected by the earthquake [15] OHC. Esposito et al. [26] reported that testing and repair of more than 70% of the gas network in L'Aquila was completed within 3 months of the earthquake, but work on these facilities was observed OHC to be still in progress during the first field visit to the area in 2010. Furthermore, the installation of water, gas and electricity facilities must have been easier OHC than inside the HC. Meanwhile, the lack of public transport and mobility issues still represent some of the most relevant problems in the city [12].

Nevertheless, the biggest problem is related to the century-old buildings, which in most of the cases are part of the cultural heritage and needs to be rebuilt according to special conservation requirements, which can take time to be met [1,19,33,36]. Aspects related to the reconstruction works in the HC such as difficulty of access, closed roads, noise, dust and public spaces used to host machinery, construction materials and working places can discourage the return of the former inhabitants or the arrival of new ones to the HC, despite the fact that several buildings are already reconstructed.

Furthermore, there are many facilities, such as schools and offices, which need to be rebuilt to contribute to a functional living environment in the HC of L'Aquila. Before the earthquake, this HC was also the location of offices and private shared accommodation for students. This means that some householders were not physically living in those houses. The contrast between building conditions along the streets in the recovery process of L'Aquila can be observed in Fig. 11.

We can conclude that the proposed recovery index is useful to identify the spatial pattern of the recovery process in an urban area affected by an earthquake. At the same time, this recovery index allows

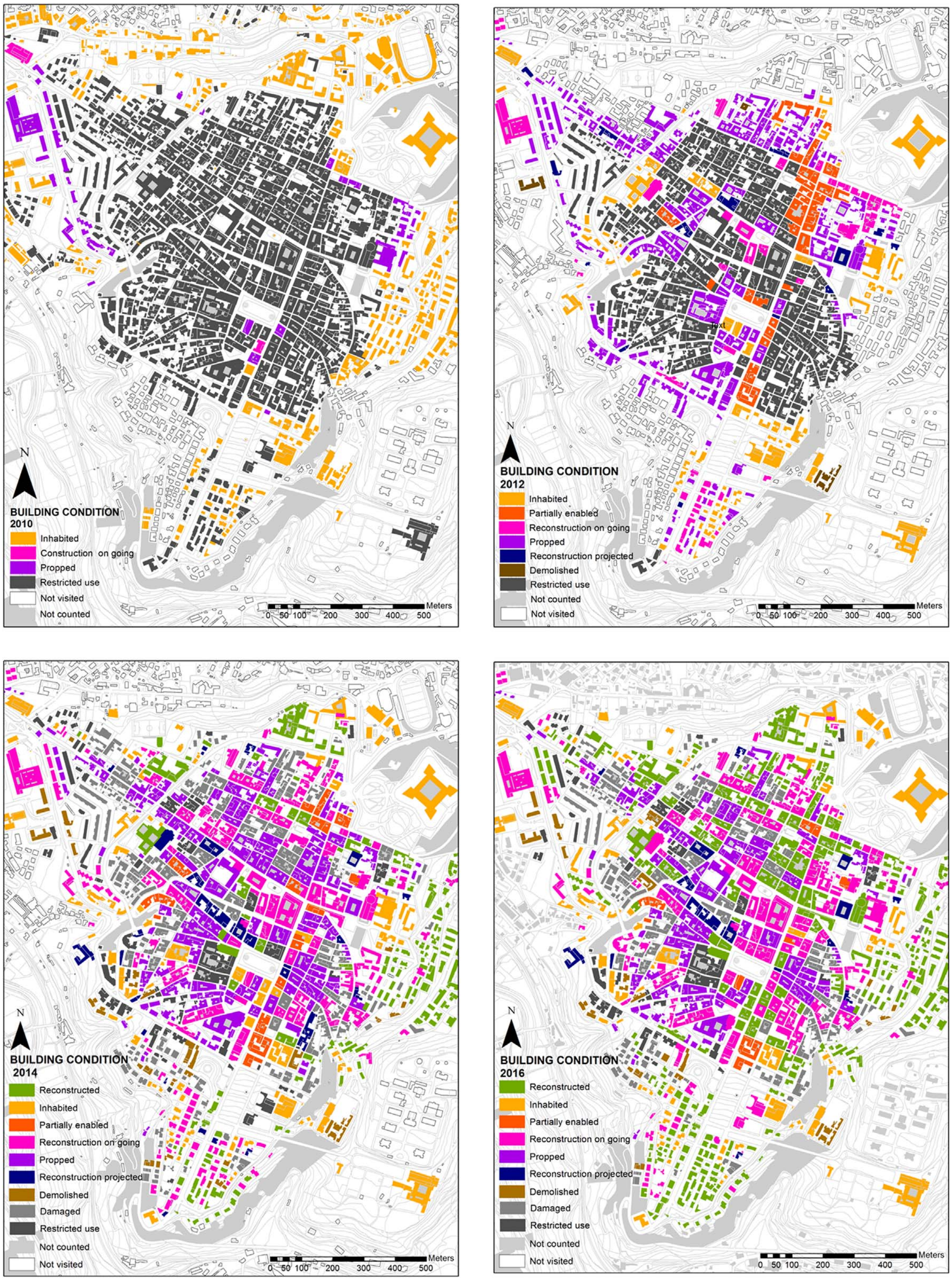


Fig. 8. Building use in L'Aquila after the earthquake in a) 2010, b) 2012, c) 2014 and d) 2016.

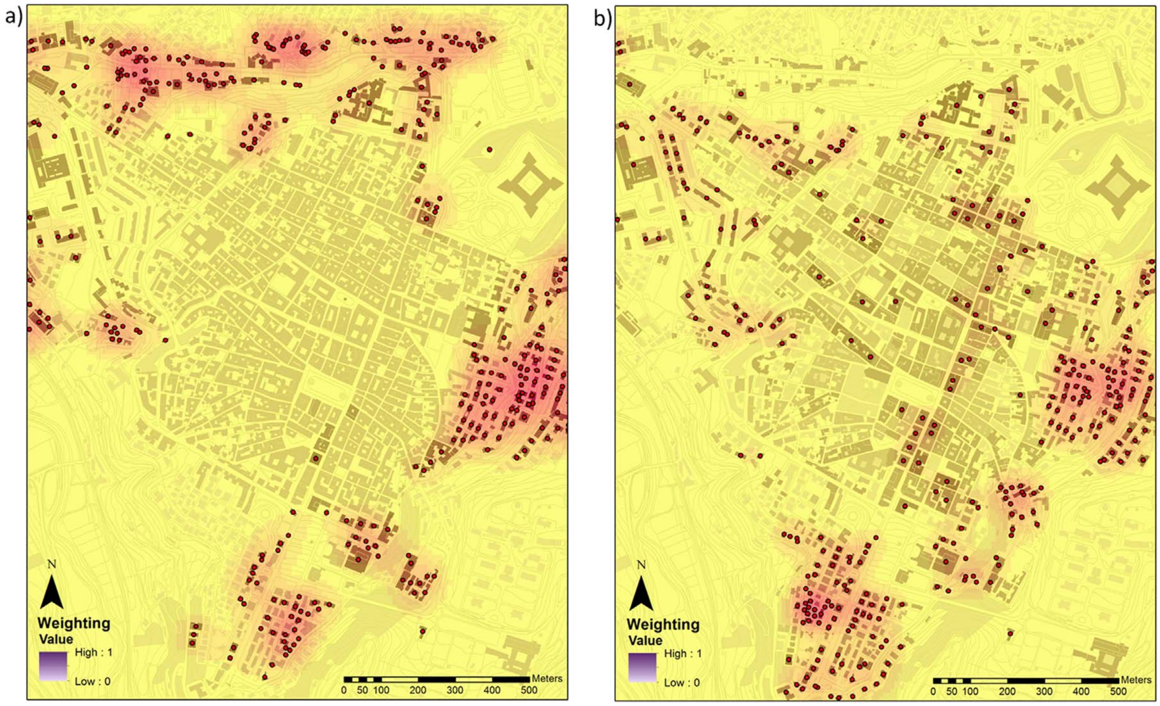


Fig. 9. Hotspots of recovery in L'Aquila in a) 2010 and b) 2016.

Fig. 10. Transitions in building condition in L'Aquila between 2009 and 2016.

us to quantify the progress in the recovery based on indicators. We plan to visit the city in 2023, when the reconstruction works of the historical city center are estimated to be finished [40]. The weights allocated by the experts are specifically related to the case of L'Aquila, but a similar weighting exercise could be undertaken in other areas affected by earthquakes, in a participatory exercise by the representatives from the institutions in the area, to set priorities for the reconstruction process. Furthermore, the proposed methodology can be applied in any area prone to earthquakes, and it can be a tool to formulate a pre-impact recovery plan. The goal is to plan and make decisions in advance to ensure a better rebuilding process. Further research can be done to investigate the reasons for the slow recovery of HC and historic buildings after earthquakes in L'Aquila and other earthquake-prone areas.

Fig. 11. Contrasts in the recovery process of the city center in L'Aquila.

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