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GIS procedure to evaluate the relationship between the period of construction and the outcomes of compliance with building safety standards. The case of the earthquake in L'Aquila (2009)

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Abstract

The earthquake (Ml=5.8; Mw=6.3) that shook L'Aquila (Abruzzo region, Italy) on 6 April 2009 and caused huge widespread damage in the other 56 municipalities of the seismic crater has also provided important input to reflect proactively on the need to avoid the repetition of similar tragedies, learning from the calamities that have occurred. In fact, L'Aquila and the other municipalities hit by the earthquake represent an open-air analysis laboratory to reveal and directly see the weak points of the different buildings on the field which did not adequately resist the shocks. In order to provide important data for social utility, in this paper we illustrate the steps which constitute a GIS procedure that we have thought in order to evaluate the relationship between the period of construction and the outcomes of compliance with building safety standards. Through sequential activities which have enabled us to also produce three-dimensional scenarios – of immediate communicative impact and able to show details for interdisciplinary analysis and strategical planning – we have portrayed the urban evolution of L'Aquila per period of construction and mapped the level of damage to the buildings. The relational analysis and quantitative data have permitted us to show that in the case of L'Aquila the major percentages of "unusable buildings", and also these together with "condemned buildings due to external risks" concern the structures erected until 1955 and then in the 1956-1975 period, followed by the ones constructed in the periods of 1976-1988 and 1989-1994. Similar results, in conjunction with other specific information, can offer the possibility to define and apply the consolidation measures necessary to tackle future earthquakes in an appropriate way, without a passive sense of resignation and with a deeper awareness of seismic risk.

Keywords: Culture of Seismic Risk, Damages, Earthquake, GIS Procedure, L'Aquila, Period of Construction, Social Utility, Three-Dimensional Models, Unusable Buildings

1. The distressing scenario after the L'Aquila earthquake

The earthquake (Ml=5.8; Mw=6.3) recorded at L'Aquila – the capital of the Abruzzo region, Italy – on 6 April 2009 caused very serious and widespread damage to its buildings and important historical-cultural heritage and shattered the socio-economic equilibrium of a city left petrified. In terms of destruction, the situation was even worse in some nearby villages characterized by the very poor quality of materials and which were practically deprived of connecting elements which facilitated their collapse, as if they were *made of paper*. The seismic crater involved L'Aquila and 56 other municipalities which constitute an open-air analysis laboratory to understand and highlight a series of problems and weak points in the solidity of the constructions which underwent excessive damage with respect to the dimension of the earthquake.

The bleak scenario (Figures 1 and 2) observed during a field survey in L'Aquila (and its hamlets), ten months after the earthquake (February 2010), was that of a devastated municipality, with a continuum of unusable buildings: a distorted and torn context, as if struck by an evil spell or by a far greater energy calamity, capable of removing the population and suddenly erasing the traces of recent everyday life. Among widespread damage, cracked walls, the overturning of parts of walls, the "bursting" of lower floors due to excessive loads, loss of floors due to the crushing and moving of pillars, in a chaos of debris and stones, one of the main characterizing elements was the shoring actions for the safety and preservation of the buildings, in a surreal atmosphere in which it is really difficult to start suitable restoration work[1].

The situation to be seen almost three years after the earthquake (March 2012), by means of a purposely conducted overflight (Figure 3), was that of a city still essentially emptied of life and waiting for organic restoration measures. An anomalous and widespread sense of inactivity persisted: the churches showed no sign of structural restoration; some buildings showed signs of temporary patching and covering of the roofs, the symptoms of a momentary dereliction status; other buildings continued to be subject to wear and tear and showed gaping walls; the propping up works and the construction sites were manifold, with a very large number of stationary cranes[2].

[1] Regarding the main results and observations during this field survey and an experience conducted in contact with a sample of the population involved see: Pesaresi and Nebbia, 2010.

Generally, it is the sad background which tends to last for years after a similar seismic event. Therefore, this was not an isolated and unusual case but is the common state that is to be found in the Italian contexts after an earthquake with a similar magnitude.

The seriousness of these reflections increases considering the following.

- "Having a potential for shallow M 7 earthquakes, the Abruzzi Apennines comprise one of the most threatening seismogenic areas of the entire Europe" (Burrato et al., 2012, p. 169).
- "The seismic strain deficit in this area was only partially alleviated by the 2009 L'Aquila earthquake sequence and continues to represent a seismic hazard in the region" (Walters et al., 2009, p. 5).
- The 2009 L'Aquila earthquake "was only a moderate seismic event" if contextualized at world scale but it provoked "disproportionate suffering" (Alexander, 2010, p. 327) which could assume impressive dimensions in case of major events.
- During the centuries, L'Aquila has been characterized by a wearing cycle of fragile becoming since many times it has been subjected to phases of destruction and inappropriate reconstruction, because it appears as the city of earthquakes, with an urban framework intertwined with the succession of disasters (Fiorani, 2011).
- Due to the 2009 event "1500 people were injured, 202 of them seriously, 308 lost their lives, 67,500 became homeless, 100,000 buildings were damaged. […]. The cost of the damage was estimated to be 16 billion Euros" according to some sources (Contreras et al., 2014, pp. 125-127) and about 25 billion Euros according to others (Monaco et al., 2012).

[2] For further information and details see: Pesaresi et al., 2013.

- Many damaged and propped up constructions in the center of L'Aquila have been forgotten for several years, that it is to say remained in the same precarious condition because no owner or authority had taken specific decisions on their retrieval, fostering uncertainty and delaying the general recovery of the municipality (Contreras et al., 2018, p. 460).
- Serious damage has been recorded by the churches and cultural heritage and it has caused a huge loss with excruciating suffering in the historical memory, at an artistic, identity and economic level, so that many studies have focussed the attention on the collapse mechanisms (Endo et al., 2015; Lagomarsino, 2012) and seismic behavior (Boscato et al., 2014; Brandonisio et al., 2013) of the churches hit by the earthquake.
- Large quantities and accumulations of rubble have been produced, which is difficult, expensive and heavy to remove and dispose of, physically and morally, to be able then to start the phases of recovery and reconstruction of buildings and the restarting of social and economic activities.
- L'Aquila has been wrapped in an expensive and thick network of trellises, scaffolding, different kinds of structural supports that made it "plaster", while several *new towns* have been built in the periphery (Simonicca, 2012, p. 31).
- For some years, important streets and squares have remained deserted, in a distressing wait, characterized only by the presence of cranes and building site noise and no longer by the voices of the people who poured into them[3].
- The post-earthquake has been marked by fear, anxiety, anguish, degradation, anger and notable setbacks have also been recorded in lifestyles, and for some years after the event "critical elements, such as the high prevalence of smoking and consumption of alcoholic beverages […], especially among young people, and very frequent physical inactivity, particularly among the elderly" have been observed (Minardi et al., 2016, p. 34).
- Relevant "rates of post-traumatic spectrum symptoms in adolescents who survived the L'Aquila earthquake" have been recorded, since having known "the loss of a close friend or a relative in the framework of the earthquake seems to be related to higher PTSD [Post-Traumatic Stress Disorder] rates and more severe symptomatology" (Dell'Osso et al., 2011, p. 59).

All this leads one to reflect on the need for different strategies and programs.

A first one could be to seriously consider the advisability of introducing compulsory insurance starting from the houses that are included in areas with a certain exposure or in any case at a short distance from these, as they could be seriously affected by events that occurred elsewhere. The insurance could be devised according to different parameters, like for example the hazard of the area and the vulnerability of the buildings[4], also considering a possible State contribution below specific levels of income.

A second need is the building of new houses according to the appropriate and recent construction rules, providing for controls that avoid speculative activities. New houses must not increase the number of vulnerable structures but guarantee adequate responses to seismic events.

A third need is to reinforce the existing constructions according to special measures regarding the entire building and the individual internal structures, by means of tax concessions and deductions. It is no longer conceivable to proceed autonomously with isolated initiatives, but it is essential to move in accordance with an organic and consistent reinforcement of the whole structure.

[3] The forced and indefinite removal from the places of one's daily life weakens the social system and tends to break down habits and certainties. The loss of the customary meeting places causes serious repercussions at the level of relationships and children, young people and the elderly must find new places, forms and opportunities for socializing and getting their strength back (Castellani et al., 2016, p. 88).

[4] A useful support can be represented by the maps of seismic microzonation, starting from the subdivision in stable zones, stable zones susceptible to local amplification (due to local lithostratigraphic and morphological structure), and zones susceptible to instability. This classification is the basis for further in-depth study. See: Castenetto, 2012.

A fourth programme could be to adopt anti-seismic norms and rules to structurally reinforce the historical-cultural heritage because every time: the losses are very expensive; the repercussions are notable even in terms of tourism; and the restoration works are extremely complex.

Figure 1. Huge damage to buildings and church roofs and the top of the walls (photos above) in L'Aquila; damage above all to the medium-low floors and failure of the external lining (photos in the center) in L'Aquila (and overturning of parts of walls in the photo on the left – at bottom); notable phenomena of collapse at Onna (photos below), a hamlet of L'Aquila. Photos: C. Pesaresi (February 2010).

Figure 2. Complex expensive propping works of single structures (photos on the left) and among facing buildings (photos on the right) in L'Aquila. Photos: C. Pesaresi (February 2010).

Figure 3. Various examples of collapse of the church roofs (which continue to show evident openings), temporary patching and covering of the roofs, thick wrapping works and presence of cranes in L'Aquila. Photos: Geographical Unit (Department of Documentary, Linguistic-Philological and Geographical Sciences) of the Sapienza University of Rome (in collaboration with GREAL, European University of Rome) (March 2012).

2. Providing data for social utility with a GIS procedure

Given the extent of the elements involved, from a methodological and applicative point of view, we have thought about contributing to the obtaining of important data on which to reflect for social utility. Thus, we have tried to verify the presence of a possible direct relationship between the period of construction and the outcomes of compliance with building safety standards.

In fact, to know whether or not in the case of L'Aquila some periods of construction have turned out to be particularly fragile – and subsequently to evaluate whether or not a similar weak point could be recorded also in other Italian contexts – can be a crucial aspect. For the purpose of promoting and supporting a structural reinforcement of the buildings, it can be very useful to understand whether or not there are some periods that – by reason of the materials used, techniques, normative framework, localized choices etc. – have experienced the development of more vulnerable structures.

To pursue this aim of evaluating the possible direct relationship between the period of construction and the outcomes of compliance with building safety standards in the case of L'Aquila, we have defined a GIS procedure characterized by different steps. It has enabled us to progressively recognize any detailed elements for a relational territorial screening.

In this way, it is possible to blend geographical theory and disciplinary contents into GIS and GIS into geographical theory and disciplinary contents, testing applied solutions and digital models functional to analysis and planning[5]. We achieved this with a three-dimensional setting and perspective able to represent together physical and anthropic components, returning an overall scenario which also supports reflections on morphological influences and construction features (Figure 4).

The first step was characterized by the comparison, interpretation and digitalization with editing activities of numerous cartographic sources and orthophotos of different periods, in order to define and digitally represent the phases of construction and the process of urban development during the time in the study area of L'Aquila.

The second step was distinguished by the use of calculation and extrusion functionalities and the creation of three-dimensional models in ArcGIS Pro environment, providing a reliable visualization of what is present on the territory with reference to the various buildings subdivided by period of construction and rendered with their height. During this step, the support of geobrowsers was important to conduct virtual flights and indirect inspections to obtain and rebuild some aspects which were difficult to have or construe.

In the third step, after a specific activity of data cleaning and data connection, the outcomes of compliance with building safety standards were mapped and interpreted and the digital representation makes it possible to observe, as a whole and in detail, the spatial distribution of the "unusable buildings" [owing to structural risk] (outcome E) and "condemned buildings due to external risks" (outcome F).

In the fourth step, we intersected and represented in ArcGIS Pro environment, and therefore in a three-dimensional scenario, the "unusable buildings" and the "condemned buildings due to external risks" by construction age classes, in order to relate the period of construction and the outcomes of compliance with building safety standards. We also repeated the process only considering the "unusable buildings" (excluding the "condemned buildings due to external risks") in order to effectively relate the period of construction with the damage directly affecting the buildings.

[5] After all "mixed-methods research with GIS" are recording fast and convulsive development since "technological innovations are easing access to data and access to visualization and analytical tools" (Preston and Wilson, 2014, p. 510) and these innovations, together with geographical approach, must contribute to create information, knowledge and critical sense. The integration of quantitative and qualitative data and methods and a focus on the details with different tools and functionalities can open "innovative and exciting ways of understanding and visualizing the multifaceted relationships between spatial phenomena" and diachronic dynamics (Yeager and Steiger, 2013, p. 1).

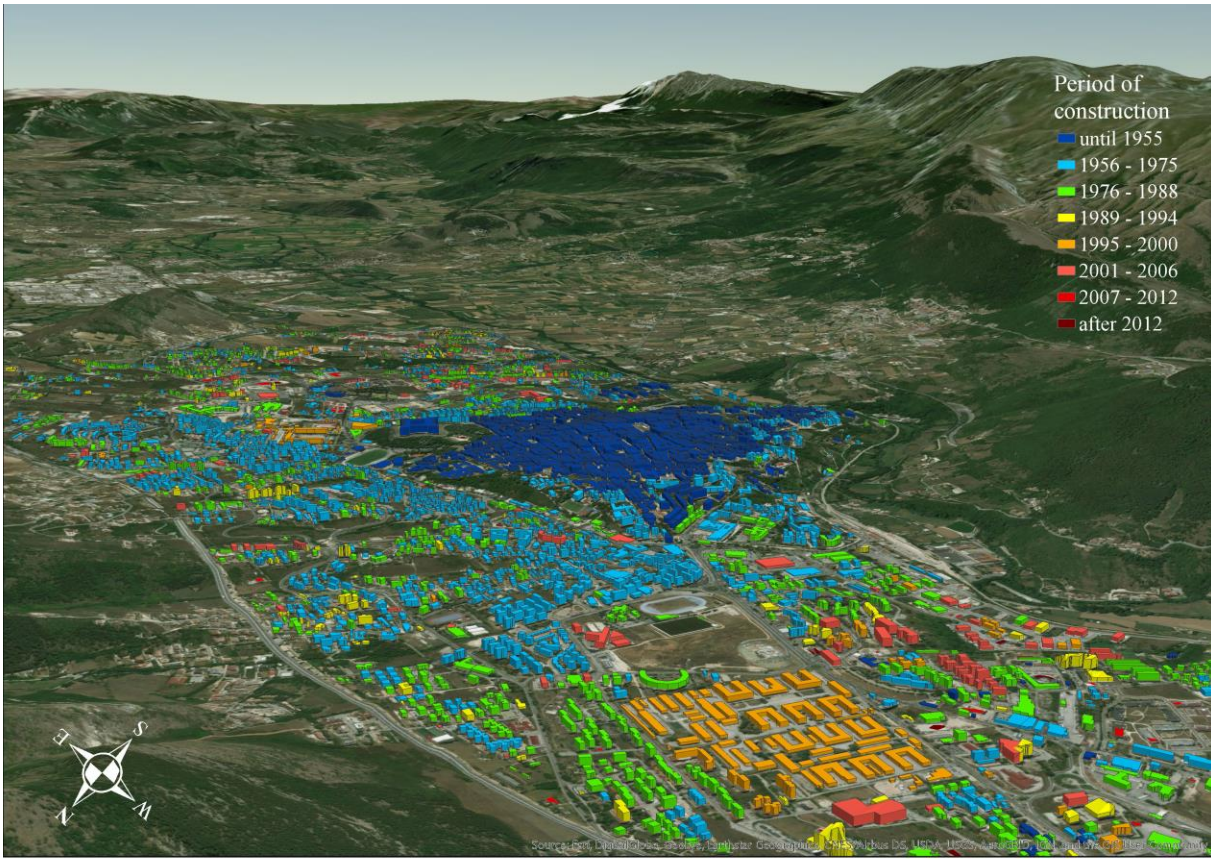

Figure 4. Three-dimensional representation of the morphological aspects and construction period of buildings in the study area of L'Aquila. Source: Authors' elaboration.

The digital elaborations and the data obtained by these phases have made it possible to conduct a relational quantitative analysis in the fifth step and to recognize the existence of some periods of major structural weakness, to which particular attention should be paid for preventive damage planning and the reinforcement operations of the vulnerable structures.

3. The five steps of the research conducted in GIS environment

The reconstruction of the evolution of urban planning, the representation of the different damage levels and the analysis of a possible existence of a relationship between the period of construction and the outcomes of compliance with building safety standards can be summarized in 5 steps.

Heterogeneous sets of data have been handled, elaborated and represented through the ArcGIS platform (in particular with the applications of ArcMap and ArcGIS Pro).

Historical and planning cartography sources[6], orthophotos and Civil Protection field data flowed into a single geodatabase and were processed with different GIS tools.

The 2D and 3D elaborations describe the phenomena and their distribution with diachronic screening effectively and immediately. Moreover, quantitative analyses enrich the study and allow us to bring out specific observations.

[6] For in-depth studies of historical cartography connected to digital and informatic techniques, see: Dai Prà, 2010; Favretto, 2012; Rumsey and Williams, 2002.

3.1 First step

The first step consisted in the reconstruction of the building process in a large area in the municipality of L'Aquila – about 27 kmq and 27 km of perimeter – in a diachronic way with the integration of several sources.

In particular, official cartography of the *Istituto Geografico Militare* of 1955 and the *Piano Regolatore Generale* of 1975 were studied and georeferenced, then orthophotos from the '80s to the first decade of 2000 – available as open source data on the *Geoportale Nazionale* site[7] – were interpreted[8]. Thanks to the high detail of the cartographic scale and the optimal photographic resolution it was possible to distinguish single buildings of the study area and to understand in which period of construction they were built.

Subsequently, intensive digitalization activity allowed us to edit as many polygons (around 6,000) as there are the constructions in the area considered, so that each polygon flowed into a specific period of construction classes.

Two GIS elaborations (with double level of aggregation) – that cover the period from "until 1955" to "after 2012"[9] – show the phenomenon.

The first elaboration divides the period into 8 classes ensuring detailed examinations. It is possible to analyze different trends of urban evolution, in an attempt to have an in-depth understanding of the changes between different construction periods. The major availability of orthophotos of the '90s and 2000s allow us to represent different screening of urban evolution in important periods characterized by a notable housing increase.

The second elaboration, with 6 classes, gives a more immediate interpretation of the phenomenon. It is often very useful to first of all try to understand the macro differences and then analyze them in detail. Starting from a general view to arrive at meticulous analyses is, after all, a good geographical gateway.

3.2 Second step

A key variable to calculate how many unusable cubic meters there are for each period of construction and to create three-dimensional elaborations was the height of the buildings.

The *Carta Tecnica Regionale Nazionale* (CTRN) of 2005 – available as open source data on the Geoportal of the Abruzzo Region site[10] – served this purpose. In fact, the table of contents of the shapefile of CTRN data has specific fields from which the height can be calculated. Considering that one polygon could have more than one height of eaves and/or more than one height of base, the average of the height of eaves and height of base for each one of the CTRN polygons were calculated. In this way, we have obtained a unique value of height for every single construction.

This value was joined to the table of contents of the shapefile of the polygons previously edited for the reconstruction of building process. Then, a field named "Volume" was created and through the *Calculate geometry* tool we obtained the cubic meters for each polygon and each period of construction until 2005 (because the last available CTRN is dated 2005).

The CTRN data did not provide the height of all constructions present in the area. In this case, the Google Street View Imagery[11] gave us precious information owing to the high level of detail whereby we obtained the number of floors of every single building. So doing, we allocated a conventional value of 3 meters per floor in order to obtain an indicative value of height.

The work done in ArcMap was integrated on the ArcGIS Pro environment, that ensures many opportunities for geographical studies. First of all, with ArcGIS Pro it is possible create three-dimensional scenarios able to bring out the landscape morphology and to better understand the real geographical context of the study area. Moreover, it produces a more realistic output that, instead of two-dimensional images, can have a greater impact especially in environmental risks studies. The extrusion allowed us to bet-

[7] http://www.pcn.minambiente.it/mattm/visualizzatori/.

[8] Regarding the importance of orthophotos and remote sensing approach to analyze urban development see for example: Fea et al., 2016.

[9] The reconstruction of the building process has been conducted until 2015.

[10] http://geoportale.regione.abruzzo.it/Cartanet.

[11] To estimate building heights from Google Street View Imagery see: Diaz and Arguello, 2016.

ter represent the building texture, the more densely constructed areas and to observe the difference of height for period of construction.

The reconstruction of the building process (Figure 5 – A and B) supports the distribution analysis of the buildings, divided into 8 different classes regarding the period of construction. Observing the elaboration, it can immediately be understood that everything built "until 1955" is the old city center, while the buildings of "1956-1975" are around old city center, and in particular in the northern area of the municipality. In the south-west there are many industrial structures built in the "1956-1975" period. These first two periods record the highest cubic meter values. In the rest of the city there are no areas characterized by an agglomerate of buildings of a unique period of construction. In fact, the polygons are scattered over the territory unevenly.

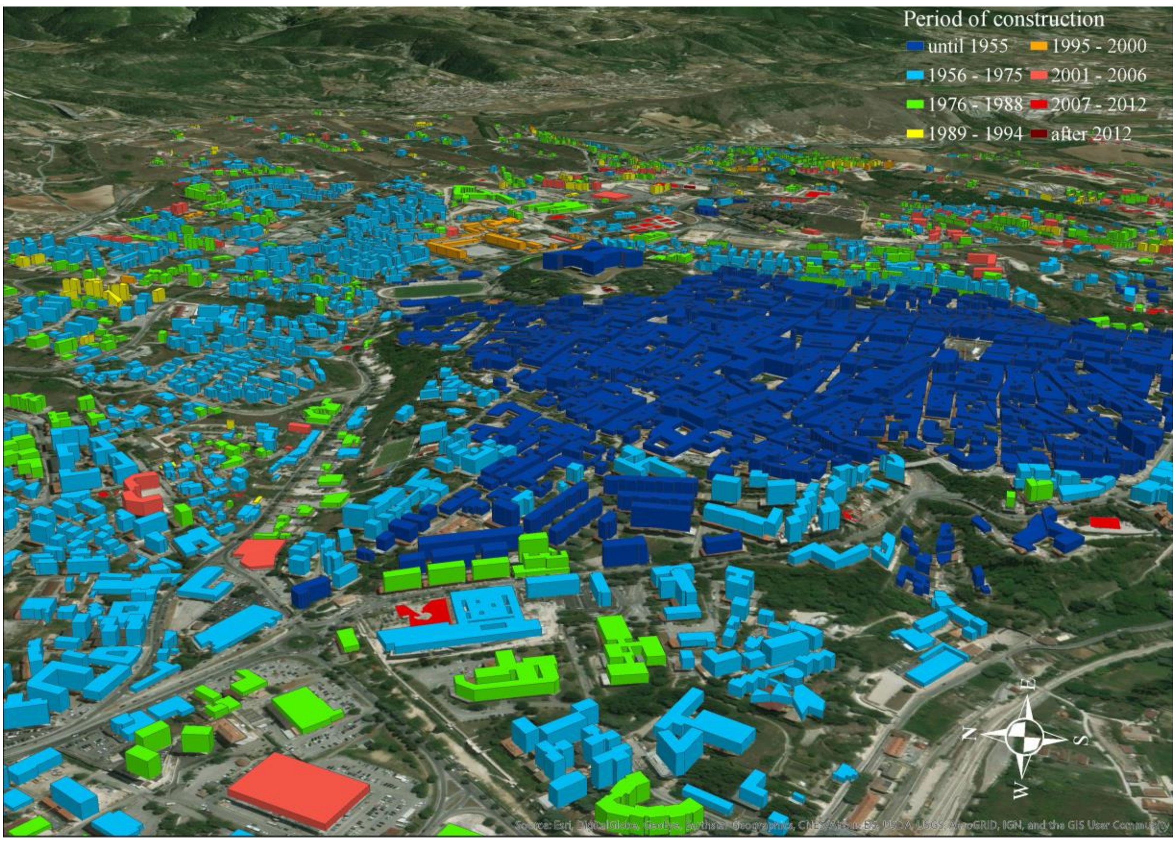

Figure 5. Here, a detail of the three-dimensional representation of the buildings period of construction in the study area of L'Aquila (A).

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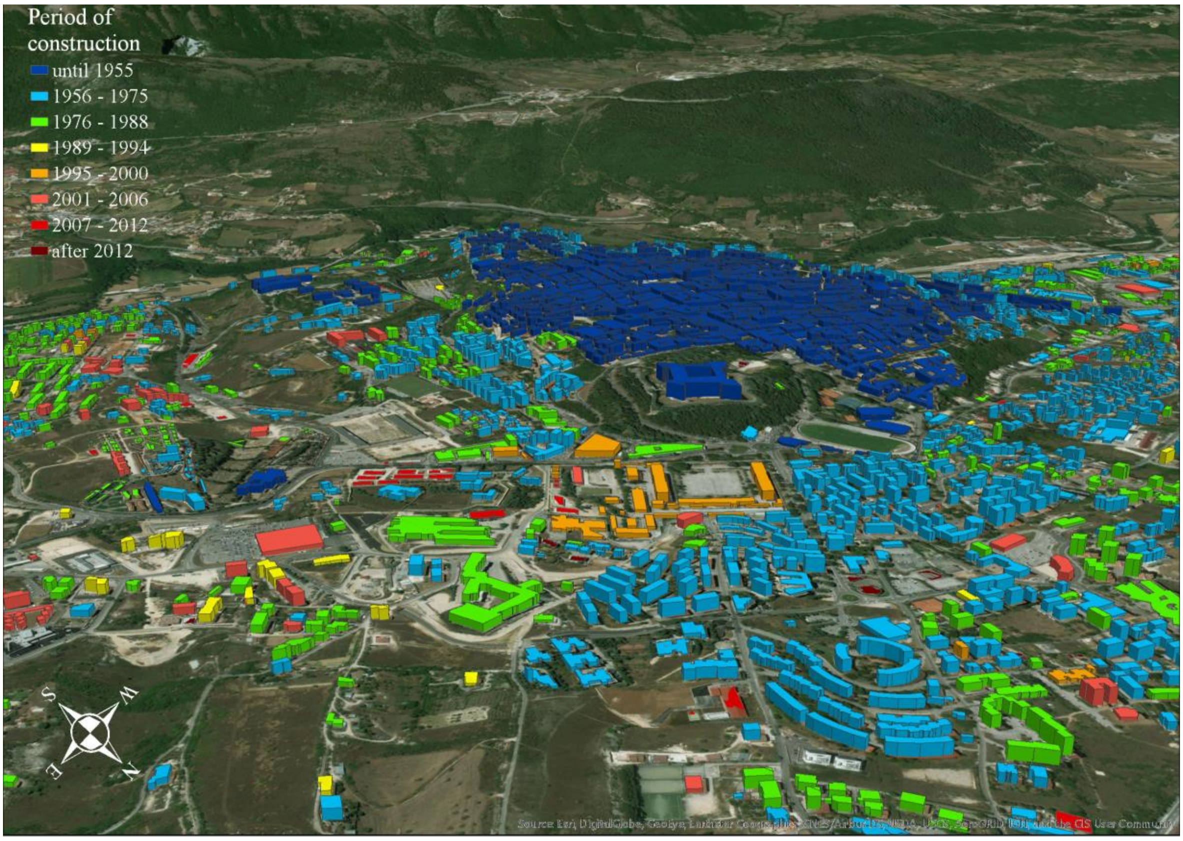

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Here, a further detail of the three-dimensional representation of the buildings period of construction in the study area of L'Aquila according to another perspective (B). Source: Authors' elaboration.

3.3 Third step

The outcomes of compliance with building safety standards are field data of the *Direzione Comando e Controllo* (Di.Coma.C.) of the Civil Protection, useful to give information about the levels of damage of buildings caused by the earthquake. They have a very strict rules to establish which houses must be secured. This data – which was kindly provided in .shp format by the Civil Protection – was imported into ArcMap and processed with data cleaning functions and data connection.

Firstly, the polygons that represent civil buildings, religious buildings, towers and bell towers, buildings which are being built and agroforestry buildings were selected with the *select by attribute* tool on the field "DESC" present in the table of contents of the shapefile data. Then, a new selection was made on the previous one to divide and categorize – with appropriate colors – the polygons on the basis of their outcomes of compliance with building safety standards. In so doing, we can see the construction distribution for outcomes of compliance with building safety standards, pointing out the areas with more damaged buildings (Figure 6).

In the legend there are 6 outcomes of compliance with building safety standards and 2 other classes: "without outcome" and "multiple outcomes". The first one shows the buildings without outcomes of compliance with safety standards because it their damage level has not been verified. It should also be noted that polygons edited by the Civil Protection can sometimes represent a cluster of surrounding buildings. In this case, each building can have a different damage level, so a polygon can include different outcomes of compliance with building safety standards. For this reason, the "multiple outcomes" class was created.

The elaboration shows that the concentration of "unusable buildings" [owing to structural risk] (E) and "condemned buildings due to external risks" (F) is to be found especially in the old city center and in the northern area.

In the old city center there are also many "multiple outcomes", while in the rest of the study area there is a mix with safe buildings (A) or buildings with partial or temporary damage (B, C and D).

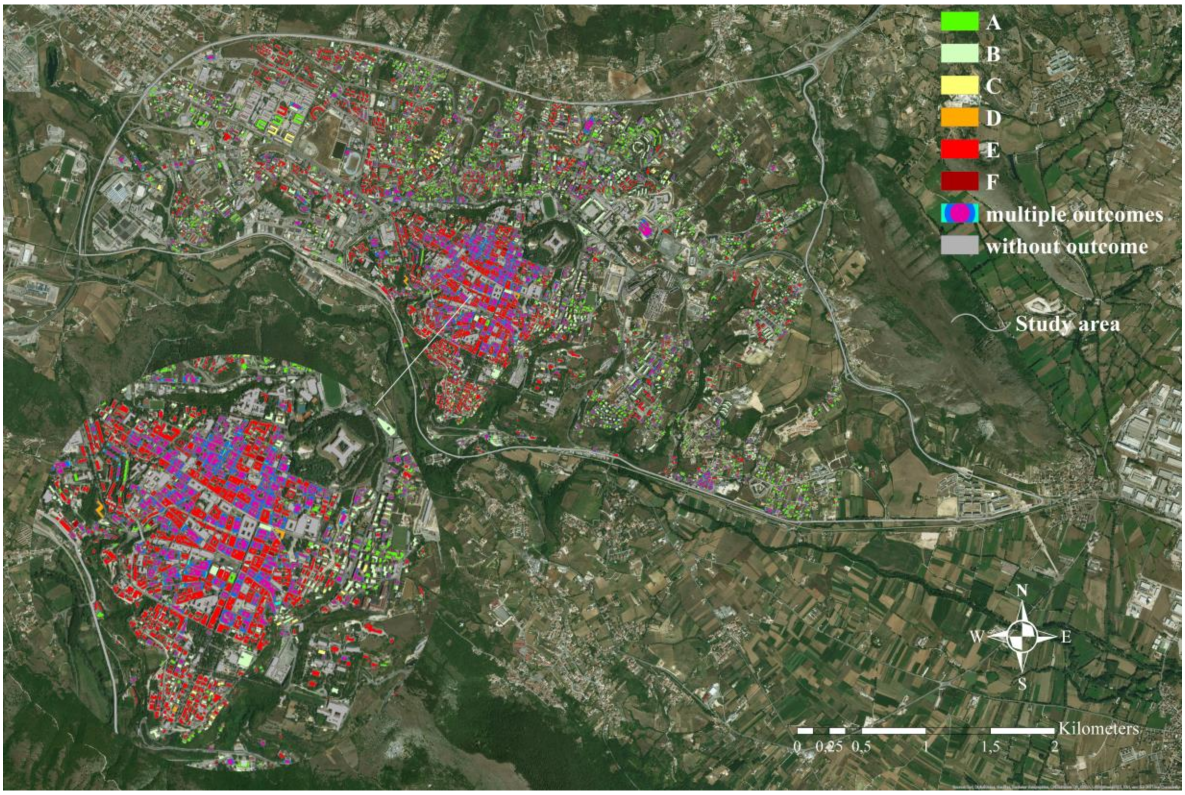

Figure 6. The outcomes of compliance with building safety standards in the study area of L'Aquila (in the circle a zoom extracted from the map). Source: Authors' elaboration.

3.4 Fourth step

To verify the presence of a possible direct relationship between the period of construction and the damage level, in this step we tried to connect these variables in order to carry out a joint study.

Firstly, we selected the polygons that represent "unusable buildings" (E) and "condemned buildings due to external risks" (F); subsequently, with the S*elect by location* tool, we intersected the previous selection with the polygons edited for the reconstruction of building process. With this function we obtained the "unusable buildings" and the "condemned buildings due to external risks" divided into period of construction classes in order to identify more vulnerable periods.

The 3D elaboration (Figure 7) shows that the seismic waves especially leave "unusable buildings" and "condemned buildings due to external risks" for the construction periods "until 1955" and then "1956-1975". Therefore, the old city center and the area around it had many seriously damaged buildings because of structural weakness and poor quality construction materials.

The same process was repeated only for "unusable buildings" (E), and therefore excluding structures with outcome F because they are subject to damage recorded by other buildings (Figure 9). In this case too, the most vulnerable periods are "until 1955" and then "1956-1975".

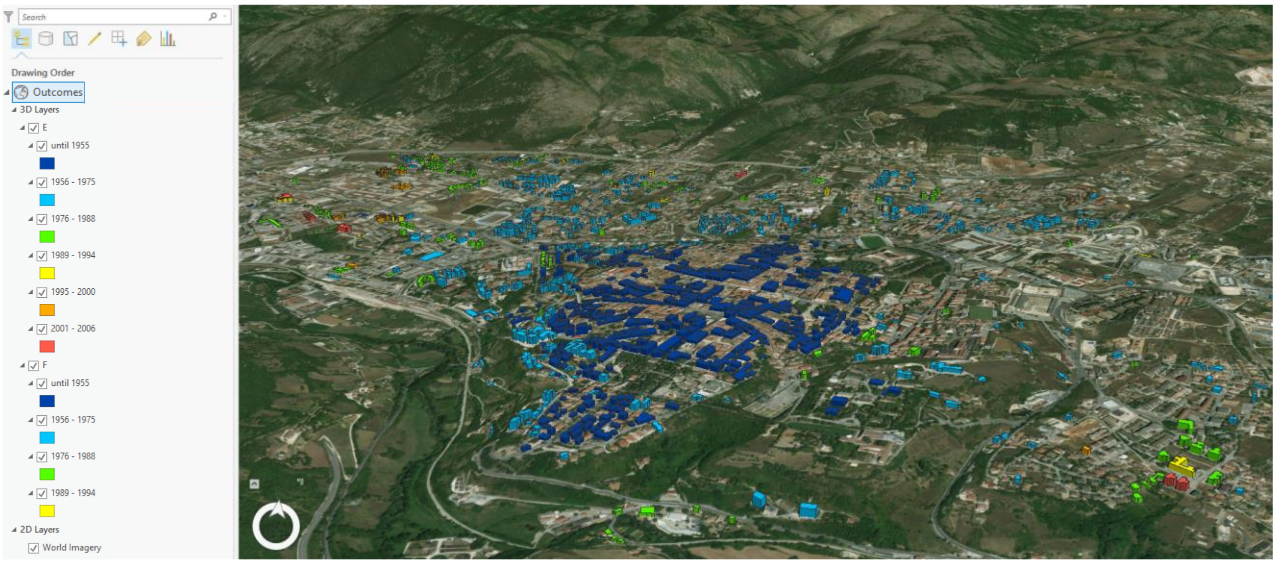

Figure 7. Outcomes E and F for period of construction in the study area of L'Aquila. Source: Authors' elaboration.

Figure 8. Quantitative data (%) regarding outcomes E and F with respect to all other outcomes for period of construction in the study area of L'Aquila. Source: Authors' elaboration.

3.5 Fifth step

One of the great benefits of GIS systems consists in complementing quantitative analysis to qualitative elaborations, to give more detailed information and useful screening of diachronic trends of phenomena. For this reason, by calculating how many cubic meters are unusable and condemned due to external risks out of the total number of cubic meters built for each period of construction has enabled us to achieve the aim of identifying a possible direct relationship between the period of construction and the damage level. Particularly, we have operated in two different ways producing two connected series of pie charts: considering outcomes E and F (Figure 8); and considering only outcome E (Figure 10).

In both cases it results that the cubic meters of "unusable buildings", and these together with "condemned buildings due to external risks" diminished over the years.

In one case, the highest value of cubic meters of outcomes E and F regards the period "until 1955" and it is equal to 41%. The value becomes 33% in the following twenty years, "1956-1975", and it decreases during "1976-1988" (23%) and "1989-1994" (22%). In the successive two periods, "1995-2000" and "2001-2006", the values decrease respectively to 14% and 9%. Considering all periods ("until 1955-2006"), the cubic meters regarding "unusable buildings" and "condemned buildings due to external risks" are 31% of the total of cubic meters built.

In the other case, the percentage values are very similar to the ones of the previous analyses (since the influence of the amount of "condemned buildings due to external risks" appears very low). In fact, the highest value of cubic meters of the outcome E regards the period "until 1955" and it is equal to 41%. The value is 31% in the "1956-1975" period, and it decreases during "1976-1988" (21%) and "1989-1994" (20%). In the successive two periods, "1995-2000" and "2001-2006", the values continue to be respectively 14% and 9%. If we consider the whole period "until 1955-2006", the cubic meters concerning "unusable buildings" are 30%.

4. For a deeper culture of seismic risk

Raising the awareness of the population and the institutions towards the need to operate in an organic, programmatic and concrete way is essential, in order to intervene preventively, to avoid future seismic events from assuming the dimensions of new inexorable tragedies. It is fundamental to develop and spread a deep-rooted culture of territory and risk, beginning the work of dissemination which must be functional to avert the perpetuation of such dramas. To implement and materialize appropriate interventions, widespread educational action is necessary that, starting from the ruinous experience of the past, can be translated in full awareness and in a new way to face a seismic event.

"Seismic adjustment is […] an outcome of group norms that are transmitted by the media and other actors in people's social environments. Seismic adjustment is also linked to the extent to which relevant experts are trusted and how responsibility for earthquakes is constructed. Finally, people's sense of their individual and collective control over adjustments and their sense of efficacy and fate in relation to the impact of the earthquake shape whether seismic adjustments are adopted or not. All of these factors are sensitive to local cultural and political contexts. These should be considered in disaster risk reduction planning and implementation as a means to increase the uptake of seismic hazards adjustments. Educational material that provides information on seismic adjustments must be designed in a way that reduces both fatalistic and overly optimistic attitudes to earthquake losses" (Solberg et al., 2010, p. 1674).

The earthquake and the measures necessary to face it in an appropriate way can neither be treated passively and with resignation nor with never implemented hypothetical ideas.

Moreover, after an earthquake, the management and organization aimed at a progressive and virtuous process of harmonious rebirth is tortuous, confused, intricate and often characterized by the lack of any profitable dialogue and cohesion among the operating parts (Reggiani, 2012, p. 155).

In addition, these actions must be started and carried out in a gloomy atmosphere of sadness, amplified by the awareness that a great amount of damage and many victims could have been avoided.

Therefore: “Conceptualising earthquake preparedness as a social cognitive process can contribute to understanding hazard preparation decisions. The analysis confirmed that preparation should be conceptualised as three separate, but linked, phases: motivation to prepare, formation of intentions, and the conversion of intentions into actions” (Paton et al., 2005, p. 28).

Knowing that in the case of L’Aquila the “unusable buildings” and the “condemned buildings due to external risks” have concerned above all the structures built until 1955 and then in the 1956-1975 period, followed by structures constructed in the periods of 1976-1988 and 1989-1994 (Figures 7 and 8), gives very important information to both institutions and people for risk mitigation, enabling them to take control of their future without attitudes of inert acceptance. The data referred only to the “unusable buildings” (without the “condemned buildings due to external risks”) are even more suitable to evaluate the possible relationship between the period of construction and the damage directly recorded by the buildings. In this case too, referring to L’Aquila, the analysis confirms that “unusable buildings” have concerned mainly the buildings constructed until 1955 and then in the 1956-1975 period, followed by those built in the periods of 1976-1988 and 1989-1994 (Figures 9 and 10).

The “translation” of data into three-dimensional scenarios provides operational digital models of considerable communicative impact, endearing aesthetic result and tangible useful planning. The replicability of a 3D GIS mapping of buildings per period of construction on a vast radius could offer a precious reference to interpret in advance and to reduce – in synergy with connected data regarding for example construction materials and seismic microzonation – the nefarious effects of similar seismic events.

It remains to be decided once and for all to use the tools, the techniques, the (geo)technologies and the interdisciplinary knowledge to face calamitous events and embrace a new culture of risk.

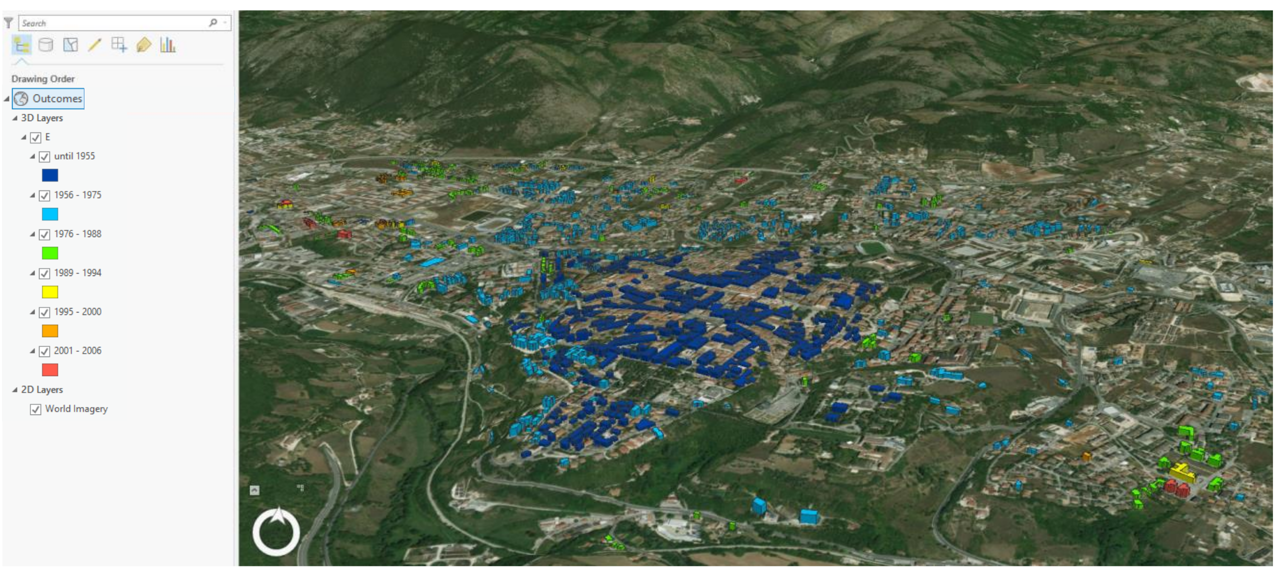

Figure 9. The outcome E for period of construction in the study area of L’Aquila. Source: Authors’ elaboration.

Figure 10. Quantitative data (%) regarding outcome E with respect to all other outcomes for period of construction in the study area of L'Aquila. Source: Authors' elaboration.

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C. Pesaresi wrote paragraphs 1, 2 and 4. D. Gallinelli wrote paragraph 3 (with all its sub-paragraphs).

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