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Remote monitoring of urban and infrastructural areas

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Abstract. Seismically induced structural damage, as well as any damage caused by a natural catastrophic event, covers a wide area. This suggests to supervise the event consequences by vision tools. This paper reports the evolution from the results obtained by the project RADATT (RApid Damage Assessment Telematics Tool) funded by the European Commission within FP4. The aim was to supply a rapid and reliable damage detector/estimator for an area where a catastrophic event had occurred. Here, a general open-source methodology for the detection and the estimation of the damage caused by natural catastrophes is developed. The suitable available hazard and vulnerability data and satellite pictures covering the area of interest represent the required bits of information for updated telematics tools able to manage it. As a result the global damage is detected by the simple use of open source software. A case-study to a highly dense agglomerate of buildings is discussed in order to provide the main details of the proposed methodology.

Keywords: catastrophic event; damage detection; GIS; risk assessment; risk management; satellite image

1. Introduction

A natural catastrophic event affects generally a large extension of land. Fifteen years ago, within the 4th European Framework Program (FP4), the project RADATT (RApid Damage Assessment Telematics Tool) discussed the possibility of approaching the problem of collecting and managing information by remote vision tools (Gamba, Casciati 1998). The literature emphasizes several contributions along this line by Anagnostopoulos *et al*. (2008), Kappos *et al*. (2010), Maruyama *et al*. (2012), Miura *et al*. (2013), Taskin *et al*. (2011) and Xiaohua *et al*. (2012). Recently the LdV Transfer Innovation "VET" investigated again the possibility of managing the rescue teams soon after the catastrophe and to monitor the situation *in situ* by vision based remote sensing. Indeed, in highly dense agglomerate of buildings and infrastructures networks, most of the damage depends on the magnitude of the event itself, but also on the lack of coordination between rescue teams and emergency agency (Bortoluzzi *et al*. 2013). The availability of a tool able to manage and to control the situation in near real time after an event, becomes a powerful help toward saving human lives and preserving the critical nodes and the

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architectural heritage.

In order to achieve such a tool, many "components" coming from different sources (as structural building information, remote sensing, earth-science, GIS system, image processing techniques, etc.) have to be integrated in a single and common software. It is worth noting that, when available, the tool can be also used as a "prevention tool". Indeed, a simulation of a catastrophic event could be generated. In this way one can evaluate the ability of the emergency agency in taking decisions and the effectiveness of the rescue teams. Furthermore the simulation tool could also be used to teach the correct way of behaving to the citizens when a catastrophic event has occurred. In (Balkaya *et al*. 2012) the two ways of exploiting the tool was already discussed. It can be used for *risk assessment* (i.e., as a pre-disaster tool) for the preparation of an inventory of maps, an assessment of existing buildings, etc. or for *risk management* (i.e., as a post-disaster tool) for the management of the crisis when supported by high resolution satellite images of the affected area in almost real time.

The aim of this paper is to introduce a tool based on application, developed on open source software,able to monitor an urban or an infrastructural area after a catastrophic event as a typhoon or an earthquake, but also to serve as a useful pre-disaster tool.

2. Governing relations

2.1 The concept of risk

In the engineering fields, risk (Casciati, Faravelli 1991) is defined as the condition which causes injury to the people, damage on plants, buildings, transport networks and so on, loss of material or decreased ability to perform a predetermined function. Since the concept of risk is subjective and it is usually related to political decisions, the quantification of a tolerable amount of it changes from time to time. Therefore, risk analysis has to be seen as a helpful technique able to operate within allow able limits. Thus, risk analysis can be simply used to identify, to define and to evaluate a likely catastrophic event. One can also give to the risk a mathematical interpretation. To do this, a pattern has to be followed introduce the natural hazard H_i, the probability of its occurrence $P(H_i)$, the consequent damage D_j for a given system, the change of the status of service S_k due to the damage D_j and its consequence $C(S_k)$. Finally the level of the risk R can be evaluated as:

$$R = \sum_i P(H_i) \cdot \sum_j \sum_k P(D_j | H_i) \cdot P(S_k | D_j) \cdot C(S_k). \qquad (1)$$

2.2 The concept of vulnerability

The concept of vulnerability is strictly correlated to the features of the exposed goods. The structural vulnerability is defined as the probability of failure of the structure related to specific hazard intensity. A simplified approach may be also adopted and a "vulnerability form" for the assessment of the vulnerability of the given system is used. This form has to be properly filled in with the main features of the system. The Italian experience (Casciati, Faravelli 1991), the Turkish experience (Balkaya 2002) and the Federal Emergency Management Agency (FEMA 2013) experience are worth being mentioned.

2.3 Remote sensing, satellite image and sensors

Remote sensing is very powerful in obtaining information from objects and it is founded on the collection and the analysis data, without the instrument used to collect the data being in direct contact with the object. Currently the satellites are the main platforms utilized in remote sensing. They have several features as carrying a wide area range of sensors, studying the weather, studying the landscapes of natural disasters, with the possibility of acquiring images also in the night light. The satellite pictures are *digital* images which are composed by several squares called *pixels*. When one analyzes a picture, each pixel comes associated with a value corresponding to the intensity of radiation reflected from the observed object within the range of wavelength in which the sensor is active. *Sensors* are devices able to acquire images. They are very different than a simple camera that can only provide the information which can be acquired by the eyes. In remote sensing, different types of radiation in the electromagnetic spectrum are exploited.

2.4 Geographic information system (GIS)

Geographic information system (GIS) integrates hardware, software and geographical data in order to capture, manage, analyze and display all forms of geographically referenced information. GIS allows one to view, understand, question, interpret and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports and charts. Moreover GIS technology could be integrated into any information system framework.

GIS stores geographic information as a collection of theme layers that can be related to each other through connection and geographical overlap (see Fig. 1).

Geographical information can be acquired in two ways: firstly by using the vector

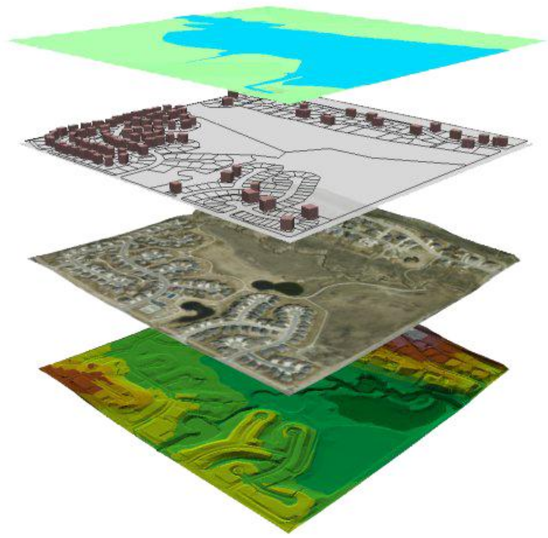

Fig. 1 Example of a GIS structure

model and secondly using the raster model. In the vector model information of points, lines and polygons are encoded and stored as series of coordinates (x, y), instead the raster model is constituted by a grid of pixels which represents a specific value. In a raster each pixel is characterized by its own grid position (row number and column).

3. System architecture and innovative features

GIS applications allow the user to analyze spatial information, to create interactive queries, to edit data maps and to present the results by these operations. *Database* is a sort of “basket” where one stores different type of information of interest. Furthermore, when one has data useful for the GIS system, they can be stored into the *database*, by using both numerical and alphabetic data. The potential of these kinds of system is the possibility to work with georeferenced data in order to extrapolate all the necessary information from the *database*. Indeed, after the operation of georeferencing, the information is physically associated with a real position in the space. The advantage of the above system is based on the possibility to have an extensive and continuous update of the database (herein the concept of dynamic database). An open source software, i.e. the *QuantumGIS* (QuantumGIS 2012) is adopted in the present work.

QuantumGIS is a software developed in early 2002 and it became an incubator project of the Open Source Geospatial Foundation in 2007. Written in C++, *QuantumGIS* makes extensive use of the Qt library. Furthermore, *QuantumGIS* allows integration of plugins developed using either C++ or Python. The software runs on multiple operating systems as MacOS®, Linux® and Microsoft Windows®. *QuantumGIS* can be freely modified to perform different or more specialized tasks. It allows use of shapefiles, coverages, and personal geodatabases. Web services, including Web Map Service and Web Feature Service, are supported to allow use of data from external sources.

The implemented system architecture can be summarized as follows (Bortoluzzi *et al*. 2013), provided two satellite images (pre- and post- event) are made available for the region under investigation:

- georeference the pre-event image using an *ad-hoc* plugin in the *QGIS* environment;
- create the layers in the *QGIS* environment;
- create the database into the *QGIS* environment;
- georeference the post-event image using the *ad-hoc* plugin in the *QGIS* environment;
- compare the pre- and post-event images using an *ad-hoc* plugin in the *QGIS* environment.

The second step after georeferencing addresses the creation of *layers* over the pre-event satellite image. These *layers* have a very important role because they represent the link between the georeferenced image and the database. Moreover, they are made by general geometrical entities as points, lines, polygons, etc., which are gathered as “shape” file. An operation of this kind in *QGIS* results very simple after the definition of the best geometry entity: if one wants to represent a building, one has to select a polygon entity and so the shape of the building from the image is traced.

The database represents the most important part of a GIS system. Indeed the *database* includes all the information related to the application. Primarily, it is worth noting that the attributes are related to a specific layer (i.e., all the photos around the area are related with the layer *photos*). In the analyzed case several parameters have been introduced in the *database*, especially structural

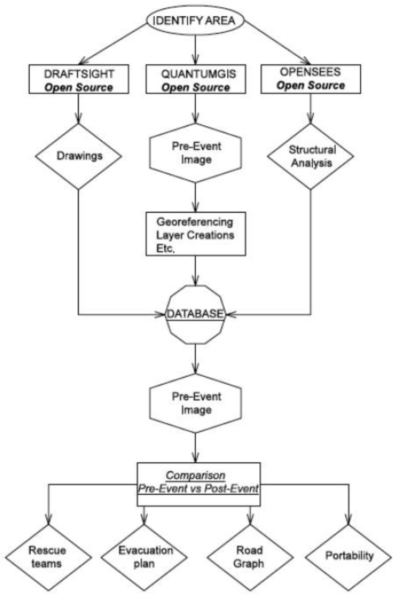

Fig. 2 System architecture

parameters of the buildings. These parameters are obtained from different structural analyses (i.e., linear static analysis, modal analysis and non-linear static analysis/*pushover*). All the analyses are managed following the requirementsprescribed by the Italian National Code (NTC08) for different magnitude of the earthquake. Furthermore other features are implemented within the database as the vulnerability index in *x*- e *y*-direction and the geographic location. Moreover the table can be filled with all the parameters available (e.g., address, city code, name/surname, age, employment of people which live in a particular building, etc.).

A further step of the proposed working procedure is the comparison between two satellite images. Several authors and software houses are working in this field in order to develop an excellent software tool able to compare images that consider all the problems related to the application field. The main issue is that almost all the software tools are under copyright and not user-friendly. In this paper the adopted visual tool belongs to the class of open source software and is still included in the *QGIS* environment. Given a photo of the area after a catastrophic event, the damage, i.e., the changes detected from a pre-event image are deducted as the variation of the pixel intensity on the photos. Hence, the first quick estimate of the extend of the damage on the area is obtained, by a simple difference, in terms of intensity, pixel by pixel between the pre- and post-event photos.

It should be emphasized that the pure identification by satellite images may present some difficulties due to image distortion (caused, for example, by smoke linked to fires, dust due to the presence of debris, etc.) that may compromise the optimal resolution. Although present, these issues may be overlooked because the tool has thought and developed as first and rapid management of the catastrophic event.

The system architecture of our proposed methodology is shown in Fig. 2:

Fig. 3 (a) Map of the city of Catania, Italy. (b) Focus on the area under study

4. A case study: the catania metropolitan area

The case study reported in this section covers the *Catania* metropolitan area, in the Italian island of Sicily (see red circle in Fig. 3(a)).

Since a satellite image for the post-event (i.e., after a catastrophic event) is not available for the region under study, it was necessary to simulate such a picture. The pre-event image was modified by a standard graphic software. For sake of simplicity, the pixels that belong to some buildings in the image were colored following these rules:

- "*black buildings*": to mark the buildings which are assumed to be fully damaged or already collapsed after a seismic catastrophic event;
- "*gray buildings*" to mark the buildings which are assumed to be partially damaged and far from collapse after the seismic catastrophic event;
- "*original color*" (no additional color to the building) to mark the buildings which do not show any consequence of the seismic catastrophic event.

Several scenarios are considered. In order to test the effectiveness of the working procedure in the area under study, the selection of the buildings which are considered as collapsed, or damaged, or undamaged is purely random. Fig. 4 shows one of the simulated scenarios.

4.1 Georeferencing the pre-event satellite image

The georeferencing operation consists of associating all the pixels of the pre-event satellite image (i.e., a raster image) to their spatial coordinates relative to a given reference system (i.e., the Datum World Geodetic System, WGS84). This operation can be regarded as an analytical correlation between two different reference systems. For carrying out this operation, one must necessarily know the coordinates of *n*-points, the so-called *CGPs*, i.e., *control ground points*, where $n \geq 3$, on both reference systems. Different *software* support tools, with *QGIS* among them are utilized. The *software* is able "to connect" the coordinates "image" with the coordinates "ground" on a georeferenced satellite image from the knowledge of the *n CGPs* (and then the correlation between the coordinates). Once the image is imported in the main interface and the frame system (e.g., WGS84) is set, a "click" of the mouse on the *CGPs* results in the assignment of their coordinates from the ground frame system (WGS84). In the procedure, the *CGPs*

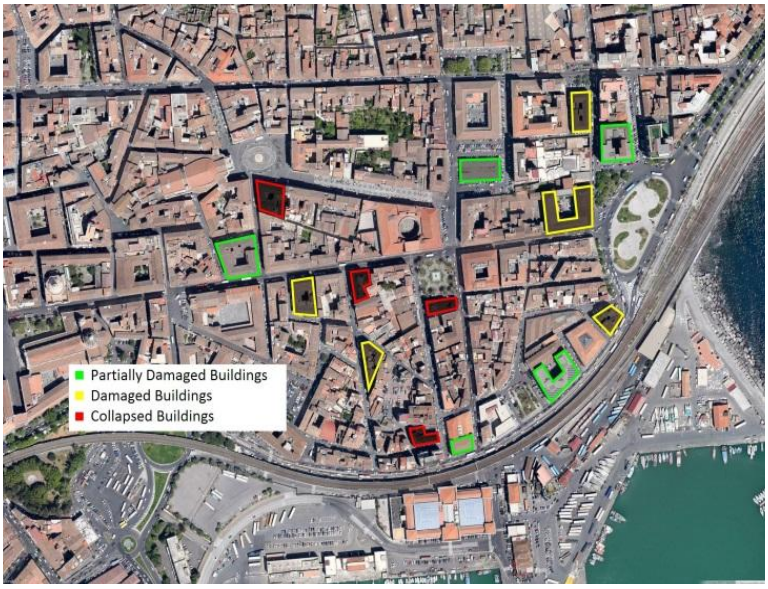

Fig. 4 Simulation of post-event scenario

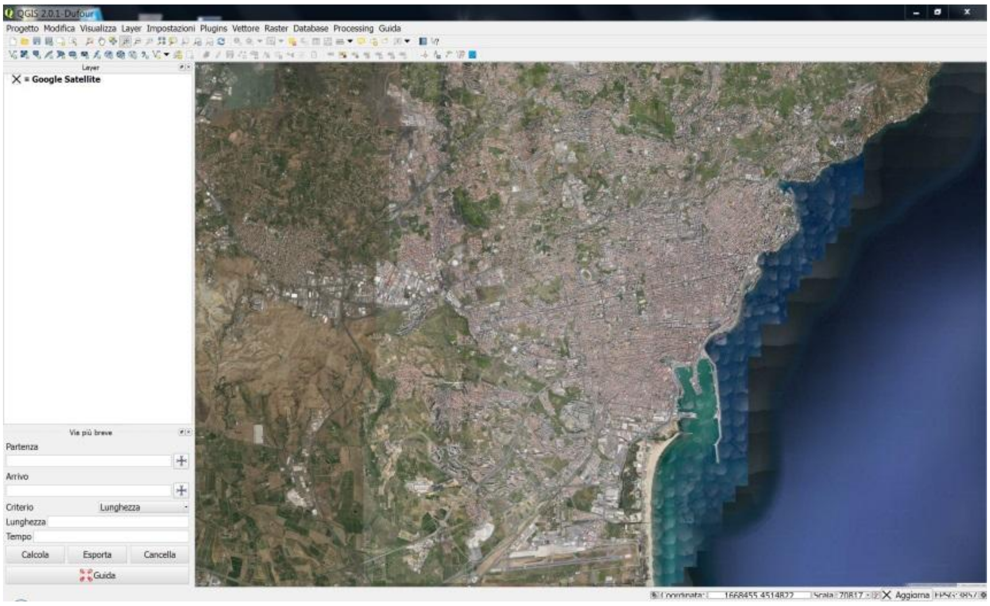

Fig. 5 *QGIS* environment in georeferencing the pre-event satellite image of Catania metropolitan are

correspond to the four points located in four main parts of the city (i.e. the soccer stadium, the airport, the harbor, the dock in the NE of the city). A *linear* transformation is adopted. An example of the first step is represented in Fig. 5. Recently a plugin that permits to georeference automatically the satellite image based on *Google Maps* has been developed.

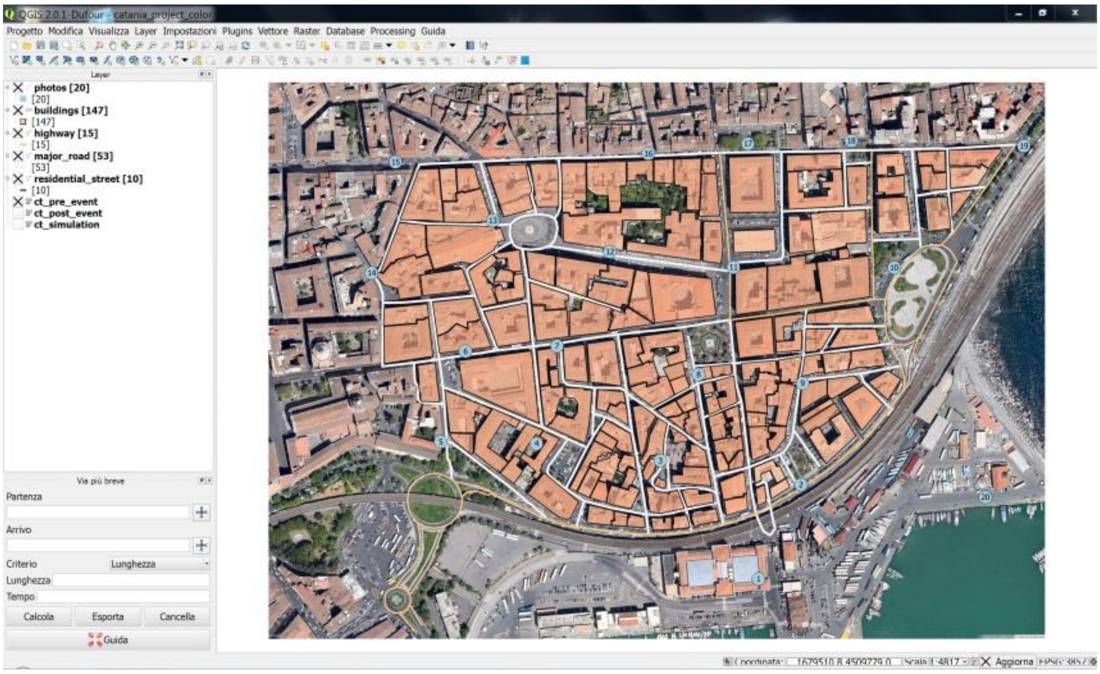

Fig. 6 Layers in the QGIS environment

4.2 Creation of the layers

For the area under investigation the following layers were created:

- *highways*: main roads surrounding the region;
- *major roads*: secondary roads tied to those listed above;
- *residential streets*: minor roads which link the access to private houses/buildings;
- *buildings*: structures to be analyzed with a link to the dynamic database;
- *photos*: gives the possibility to get an overview of the area through photos taken at the points of interest in the area (source: *Google Maps*).

Fig. 6 shows a clear example of this step. In fact, every building has been assigned to a layer orange colored, while it is preferred to divide the routes into *highways* (yellow), *major roads* (white with black outline) and *residential streets* (white) depending on their strategic importance. In addition, in every place of interest, a photo has been associated through the plugin *Google Maps*, and on the screen appears with a progressive numbered cyan circle.

4.3 Creation of the database

Fig. 7 shows an example of the *database attribute table* in the *QGIS* environment. In addition the *QGIS* software allows one to define external links, the so-called *hyperlinks*, which interact with other software in order to implement and update the information about the area. For this work, as external links, structural plants (.dwg and .pdf files), structural analyses, tables with the bearing load and finally the "evaluation form" are developed and defined, as illustrated in Fig. 8. Once the

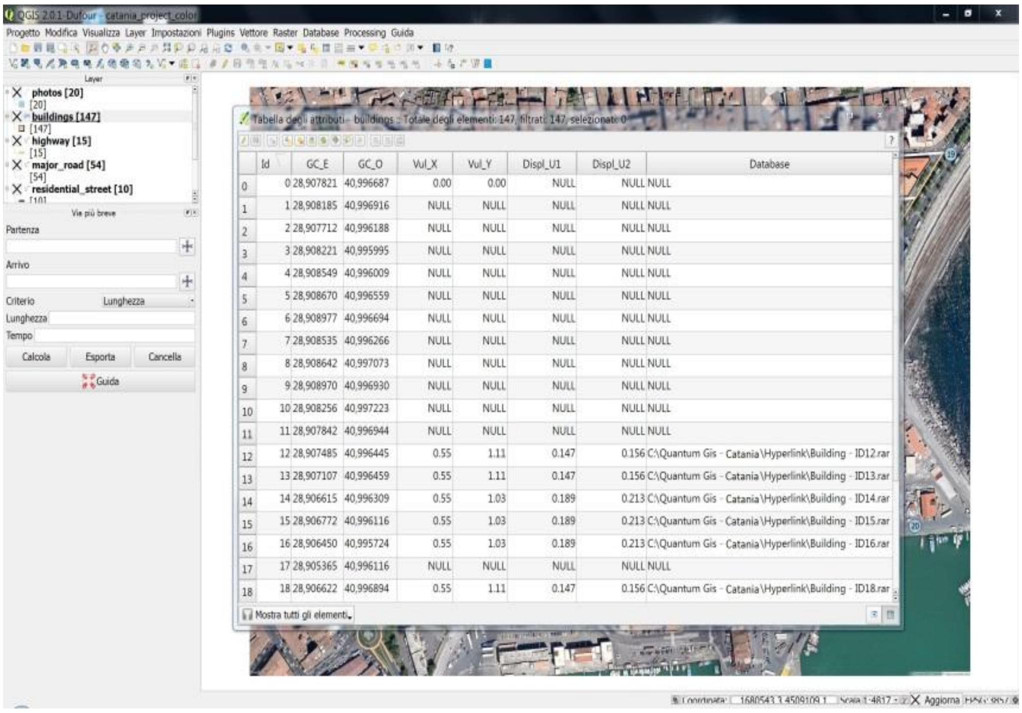

Fig. 7 Attribute table in the *QGIS* environment

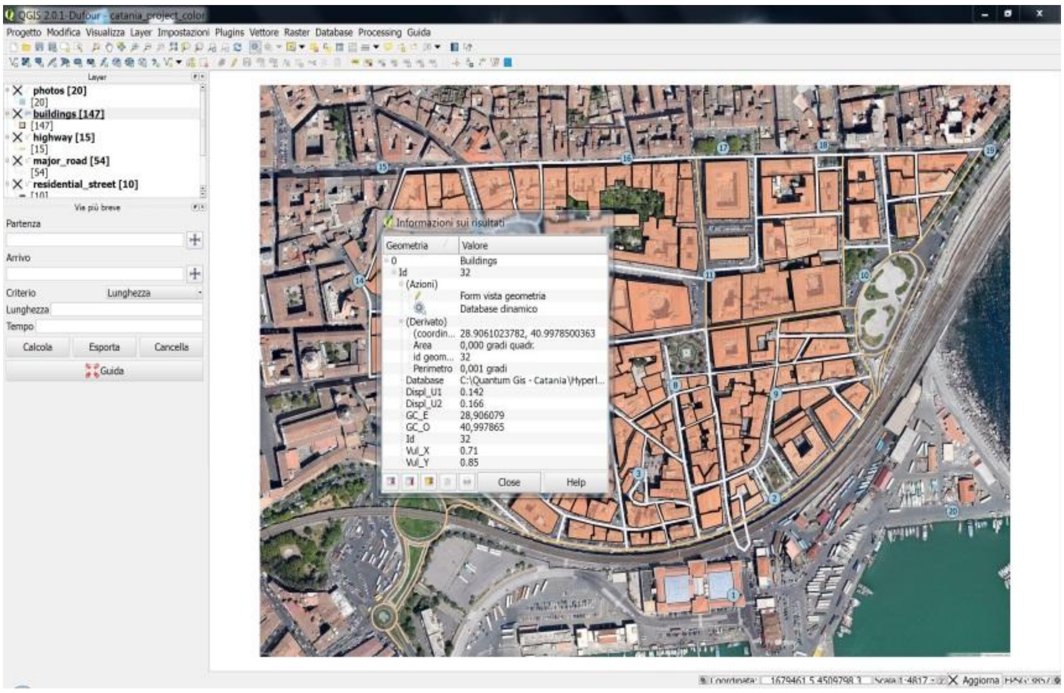

Fig. 8 Example of external link within *QGIS*

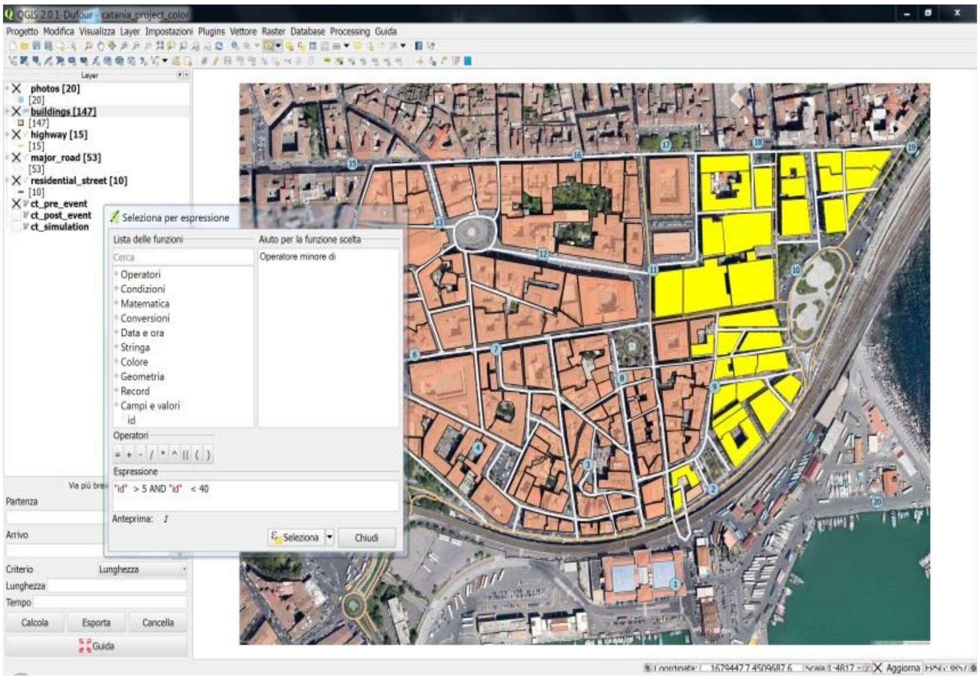

Fig. 9 Example of a query: on the left the “query” and on the right the “answer” (yellow buildings)

database is set, one can question the system with a series of queries, by the use of a particular command that directly plots the results on the screen. An example is provided in Fig. 9, in which system is required to identify buildings whose ultimate displacement before failure, computed with the pushover analysis, is less than 0.15m, which are shown in yellow color. Also for this part of the procedure, only open source software is used. In particular: *OpenSees* (OpenSees 2013) for the FEM structural analysis, *Draft Sight* (Draft Sight 2013) for the drawings, *Acrobat Reader* (Acrobat 2013) for the .pdf files and finally *OpenOffice* (OpenOffice 2013) for the management of the numerical spreadsheets.

4.4 Georeferencing the post-event satellite image

This operation is totally the same with the one described in sub-section 4.1. The *Control Ground Points* (*CGPs*) are located in the same four points selected previously for the pre-event image.

4.5 Pre- and post-event satellite images comparison

This operation is performed by an *ad-hoc* plugin within the *QGIS* environment. The higher the imager resolution is, the better the accuracy of the estimation will be. Moreover, for this case-study, the problems related to image processing (e.g., the problem of shadows, the different angle of capture, the time of capture during the day, etc.) become marginal, because it is always possible to rely on the structural data stored into the database. In addition, the structural data can also be

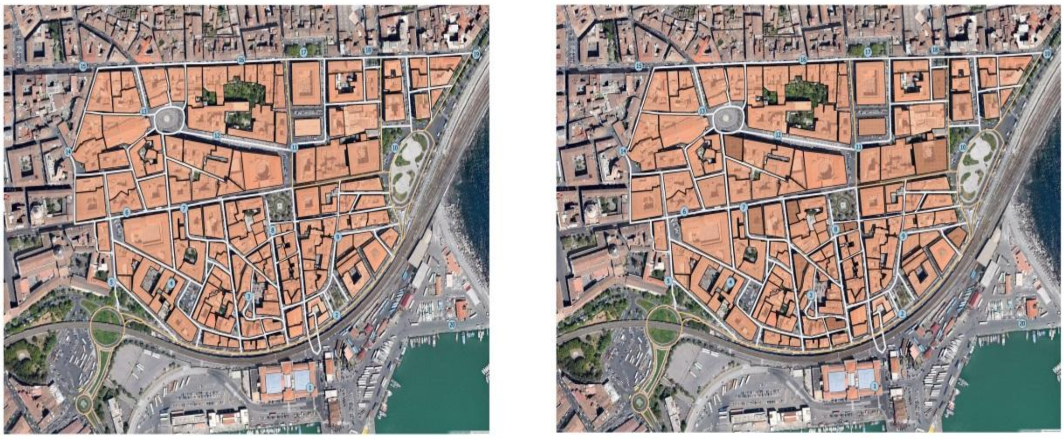

Fig. 10 Pre-event satellite picture on the left. Post-event on the right

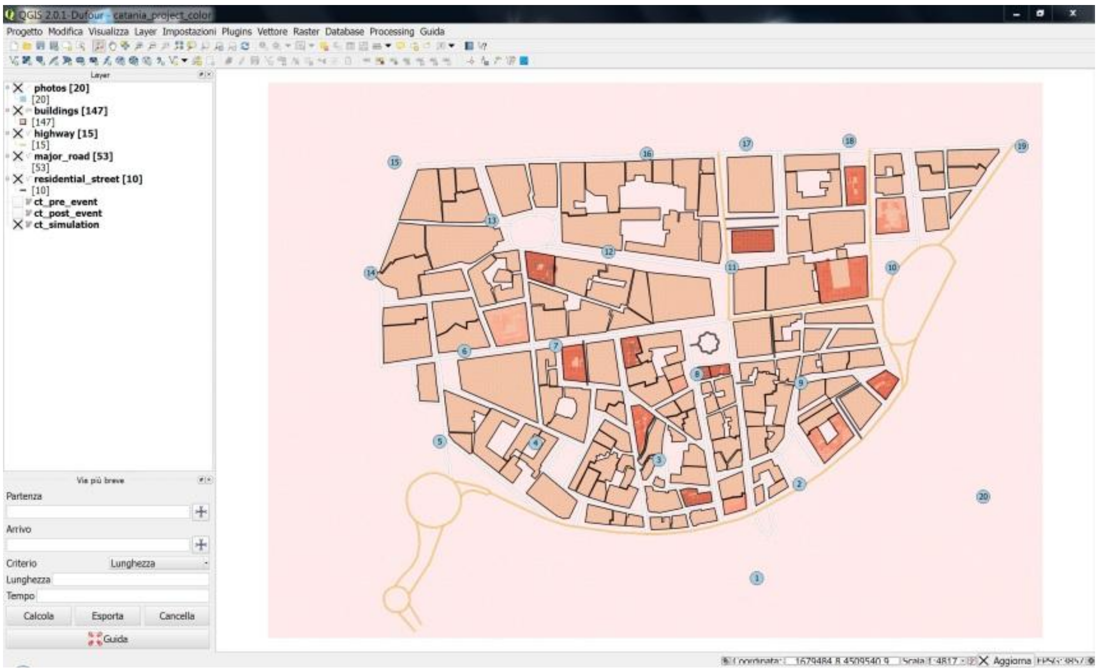

Fig. 11 Picture comparison. In “dark red” collapsed buildings, in “light red” damaged buildings

used to have the best response/prevision to a visual inspection. For example, the following parameters can be taken into account because it stored in the database (see sub-section 4.3): vulnerability index, pushover analysis, modal analysis, stress-strain analysis (such analyzes are based on hypothetical scenarios of event). Hence, once the magnitude of the event is known, a double check is developed: the first one is visual, using the pre- and post-event images as already shown (i.e., by difference of pixels) from which one can obtain a first map of damages; the second one is in function of the structural data enclosed in the database referred to in sub-section 4.3. The post-event image shows the situation of all facilities taken by the photo, i.e. buildings, roads, bridges and so forth. Moreover, the shortest and the best route from the rescue team stations to damaged buildings can be simulated. Next section will be focused about this tool. In order to test the proposed system, different post-event scenarios are evaluated. Fig. 10 and Fig. 11 show an example of comparison between the pre- and post-event satellite images.

After the identification of the damaged buildings, the proposed procedure allows one to formulate a first guess for the cost of reconstruction and to estimate if it is more convenient, in economic terms, to repair these buildings or demolishing them, which would facilitate the operations for future reconstruction. Frequently the amount of money to be spent in order to repair or re-build a building is very high and such a cost could result not affordable by a citizen in the absence of an insurance coverage (Yücemen 2005).

Such an economic estimate was developed for a Turkish database provided by the authors' partners within (www.ldv-earthquake.com) and the results are reported in (Vece 2012). Another example for the Italian database is presented in (Bortoluzzi *et al*. 2013).

4.6 Management of rescue teams

After the comparison between the pre- and post-event images, the various scenarios are defined and so one can easily manage rescue teams in order to reach, in the quickest way, the damaged buildings (e.g., private houses, hospitals, schools, hospices, etc.). If an important street is blocked after a catastrophic event, in the *QGIS* environment, there is an *ad-hoc* plugin which gives the best way to connect a point named "A" to another one named "B". This specific tool is also linked with Google Maps and it is constantly updated. This tool also results very useful in the simulation of an event. Indeed, one can predict that a route will be inaccessible after a catastrophic event (e.g., an earthquake) and can train rescue team people to select the available alternative routes.

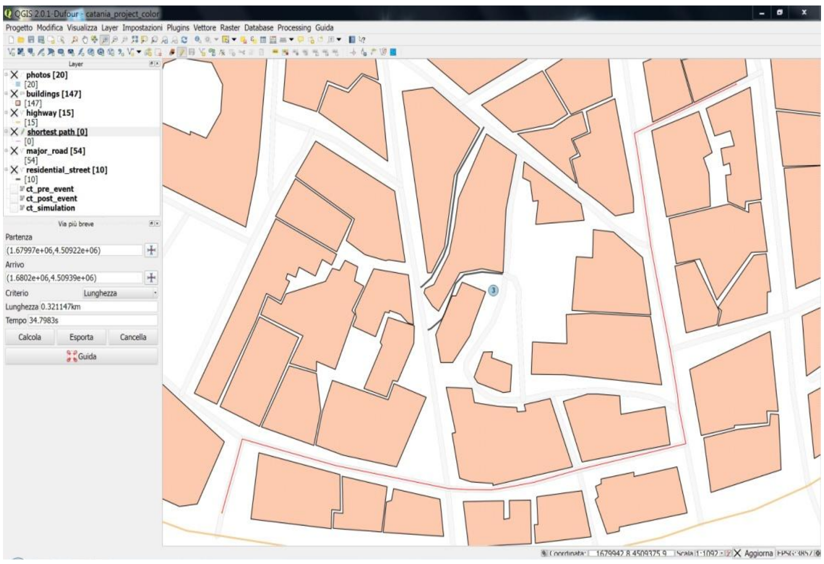

Fig. 12 Example of roadgraph within *QGIS*

4.7 Portability of the system

Indeed several operations can be made *in situ* because one can easily link the procedure developed on the PC with the smartphone in order to check the situation in real time. This provides a constant update of the situation.

Nowadays, *QGIS* is developed also for smartphones. It is available for free on Android OS.

5. Conclusions

Starting from the experience gathered within the RADATT project and updated along the LdV Transfer Innovation Project "VET", a telematics-working tool, which is able to compare satellite images of the area under study, before and after a catastrophic event is presented and discussed. The potential of the procedure is to couple a visual inspection with the structural data stored into the database in order to have the best prevision of and response to the consequences of a catastrophic event. Moreover, only open source software is used. A foreseen challenge is to make all the software independent of the hardware platform and its operating system.

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