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Journal of Research and Didactics in Geography (J-READING), 2, 4, Dec., 2015, pp. 25-37
DOI: 10.4458/6063-03

J - READING
JOURNAL OF RESEARCH AND DIDACTICS IN
GEOGRAPHY
homepage: www.j-reading.org

GIS4RISKS: Geographic Information System for Risk Image – Safety Key. A methodological contribution to optimise the first geodynamic post-event phases and to face emergencies

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Received: September 2015 – Accepted: October 2015

Abstract

In this paper we provide a methodological and operative contribution aimed at optimising the first post-event phases in case of seismic and volcanic events, as an advancement of the research conducted for the GIS4RISKS project. Particularly, we underline the importance of setting up a performant GIS platform able to synergistically use and manage data and images deriving from multiple sources to promote a system where refined methodologies and procedures converge for the development of digital representations, calculation models, spatial and multi-temporal analysis, through an integration of geomatic, engineering and geographic approaches. A synthesis of the characteristics of this platform, useful for increasing savability during the emergency phases and to better tackle situations of crisis due to geodynamic events is provided and particular attention is also given to the added value that can be derived from a coordinated use of drones (Unmanned Aerial Vehicles – UAVs), permitting a rapid recovery of detailed information in hostile areas and a rigorous monitoring of the evolution of the situation, avoiding risks for operators on the field.

Keywords: Drones, GIS Platform, Post Event, Risk Emergency Management, Savability, Seismic and Volcanic Events, Unmanned Aerial Vehicles (UAVs), Vulnerability

1. The importance of a performant GIS platform to optimise the first post-event phases

In a previous paper, the main aims, the possible progress in knowledge from the geographical and engineering points of view, the various application hypotheses regarding the GIS4RISKS project[1] and its educational purposes were highlighted (Pesaresi and Lombardi,

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[1] The name GIS4RISKS has been thought to perform the need to consider *seismic* and *volcanic risks* defining a strict reference framework useful both in the *pre* and *post event* phases.

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2014)[2]. In this contribution, some operative aspects and proposals aimed at specifically developing an integrated *Risk Emergency Management* system with high level technological innovation in a GIS platform are outlined, in order to move towards an efficient and timely management of emergencies in the immediate post-event in areas with high anthropic density and particularly vulnerable conditions. The present approach has been devised in order to meet the needs concerning seismic events, but also of volcanic eruptions, above all in the case of any partial failure of preventive measures and evacuation plans, and related urgencies.

A suitable management of the rescue phases calls for in-depth studies and tested systems for the application of analytical models aimed at the qualitative and quantitative evaluation of risk and connected damage, based on objective and reproducible estimates. The planning of an optimised management system can guarantee a considerable reduction in the number of victims in the hours and first days following the event, since a considerable decrease in the savability of the subjects involved in natural disasters can be seen with the increase in delayed rescue time.

Notable results can be, therefore, achieved by predisposing an articulate, interactive and advanced GIS platform able to create a dynamic and dialoguing system among the different structures and institutions involved in the early post-event phases, as highlighted more than a decade ago in the case of seismic events (Soddu et al., 2002; Pesaresi, 2004, pp. 249-252)[3]. So, it becomes possible to define a powerful system able to minimise the gap between the expected and the real scenarios, providing a large set of essential inputs and information to intervene quickly and efficiently, having detailed knowledge of the different geomorphological, socio-demographic, settlement and infrastructural characters (i.e. the shortest routes in terms of distance and time, also in relation to the damage) of the areas mainly affected by the event which must be included, weighed up and evaluated in specific geo-statistical models.

An integrated approach of *geomatics, geographic* and *engineering systems* can lead to the development of an "intelligent" and performance model able to plan and support the automatic management of the emergency phases in the immediate post-event, with suitably calibrated procedures that are geared to reference standards. The streamlining of the operations with the adoption of dedicated systems can in fact generate the twofold advantage of increasing the number of survivors rescued and of reducing the emergency costs.

The importance of an interdisciplinary approach is quite evident that avails of specific techniques to acquire sets of metrically correct, selected, verified and validated data from geographical research, which allow the reconstruction of logico-information schemes for the memorisation and representation of quantitative and qualitative data, producing dynamic digital mapping and combined spatial analyses. The objective is thus to define a digital model – based on geophysical-engineering and geographic-statistical parameters – which, by means of selective thematic queries, acquire new input data by implementing a virtuous iterative process of parameters estimated and calibrated by calculations and evaluations of vulnerability.

Such process presupposes the setting up of a performing server to manage:

- geological and geomorphological cartogramphies, for indispensable information of a pedological nature, on potential fragility, possible exposure to strong quakes and landslide phenomena, and technical and historical cartographies, relative to the evolutions recorded over time, the main expansion directions and the areas that have progresssively reached highly critical levels (Figures 1-4);

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[2] In fact, there is a growing need to foster a widespread and appropriate sense of risk awareness in the population by means of a didactic-educational process that should be considered a fundamental factor to valorise and diffuse the scientific-applicative progress on a wide scale, with decisive developments in order to deal with any potential dangers (Scandone and Giacomelli, 2015, p. 11).

[3] Natural "disasters are characterized by short reaction/response times, overwhelming devastation to infrastructure, and a strain on the tangible and intangible resources of the affected community" (Ware, 2007, p. 37).

- sensitive, official georeferenced data (demographic, social, settlement, economic-productive, land use) and data from direct surveys (single buildings and time of construction, results of conformity to standards of previous events etc.);
- satellite, aerial and light vehicle images and, when available, images from close-up surveys with cameras and thermal imaging cameras mounted on drones (Unmanned Aerial Vehicles – UAVs) or recordings on the ground using GPS, for a multifaceted set of crucial data.

The proposed procedure starts performing "the logical progression of data in a GIS project: (i) capture; (ii) transfer; (iii) validate and edit; (iv) store and structure; (v) restructure; (vi) generalize; (vii) transform; (viii) query; (ix) analyse; and (x) present" data in digital maps in 2D and 3D visualisations (Maguire and Dangermond, 1991, p. 324). In this way, it is possible to promote a "cartographic modelling" intended as a specific methodology and a refined system for the representation, interdisciplinary analysis and synthesis of the data recorded (Tomlin, 1991, p. 361). Moreover, the aim can be achieved of working in a "data integration" perspective which makes it possible to make different data sets compatible and overlapping, so that they become displayed on a series of connected maps and their relationships become easier to analyse in a synoptic and multi-temporal framework (Rhind et al., 1984; Flowerdew, 1991).

Starting from these consolidated "bricks", as the foundation of the general framework, the return of easily updatable and implementable models in a GIS context, with a user friendly interface and data networking, can considerably facilitate the exchange of fundamental information among research bodies, civil protection and operators on the field, who come to make up the "key players", in a network which moves towards strictly related interaction and integration mechanisms inspired by the principles of disaster management. In fact, the capacity to effectively respond to the first phases of an emergency is connected to the availability of a large amount of data and information obtained from a great variety of sources. These data must be gathered, well organised and displayed to determine, with a high level of accuracy, the size, the steps and the urgencies of the emergency management programmes. A performant GIS platform can support a virtuous mechanism to centralise, visually display in dynamic maps and analyse-interpret, with a rigorous approach, critical and combined information in the first and neuralgic post-event phases (Johnson, 2000, p. 3). Therefore, the identification of the stricken areas, a reliable estimation of the number of people involved and an organic system of georeferenced data represent essential information and some studies have shown the importance of "developing a low cost mini UAV (Unmanned Aerial Vehicle) devoted to the early impact analyses. The aim of the UAV project is to develop a low cost aerial platform capable of autonomous flight and equipped with a photogrammetric payload for rapid mapping purposes" (Bendea et al., 2008, p. 1373)[4]. In this way it is possible to have data collected near-real time post-disaster which open a whole range of perspectives to optimise the emergency first aid and some examples of value-added application in the emergency mapping domain have been recently highlighted (Boccardo et al., 2015).

As stated in the *EU Framework Programme for Research and Innovation* of Horizon 2020, in one of the topics regarding *Crisis management*, in the pillar "Societal Challenges", very relevant expected impacts, for the development of knowledge and the obtaining of concrete results, concern i.e. the necessity to increase the "capacity to anticipate, prepare and respond to disasters", enhancing the "capability to deploy disaster and crisis management assets", improving the "prevention, preparedness, response" for a concrete disaster risk reduction, improving aspects regarding the decision-making aspects, the communication and coordination of response actions, the sharing of information[5].

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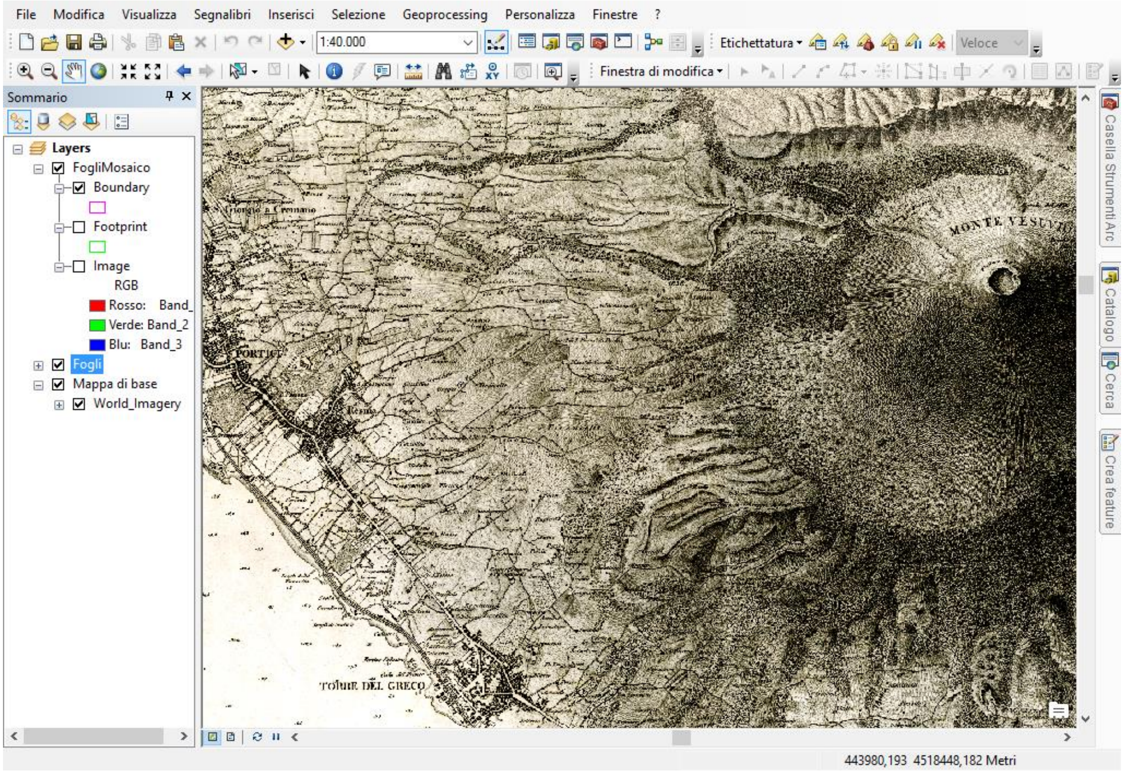
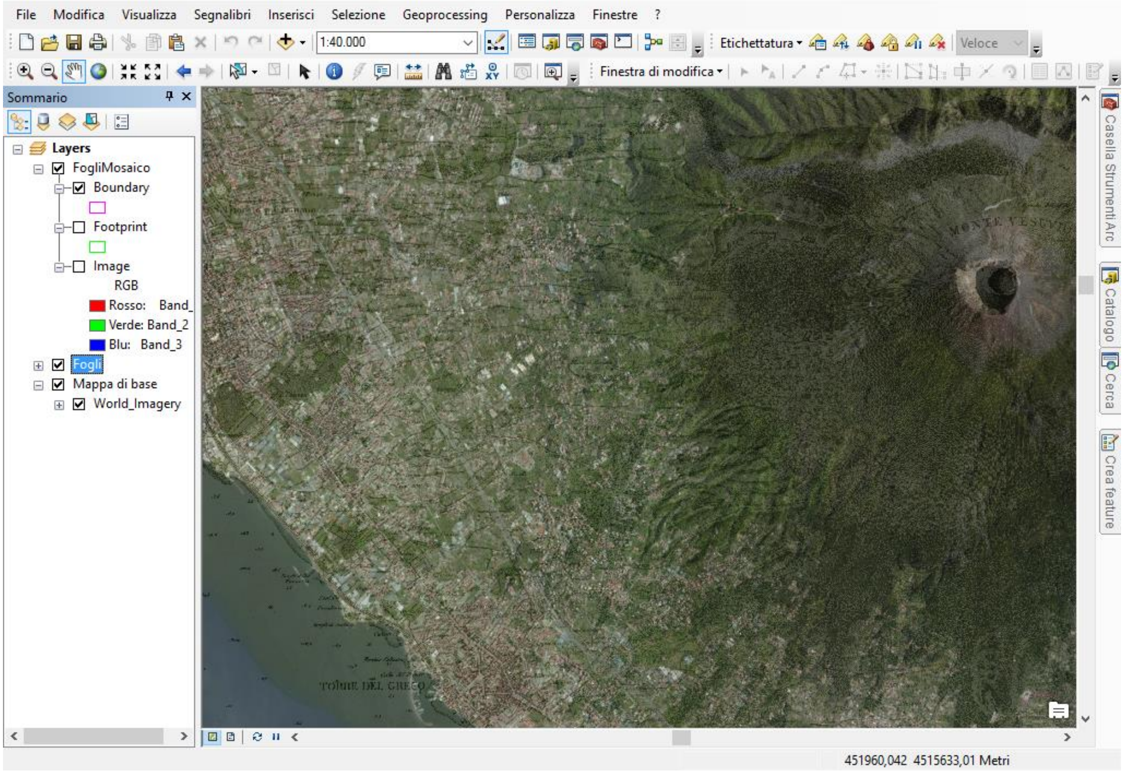
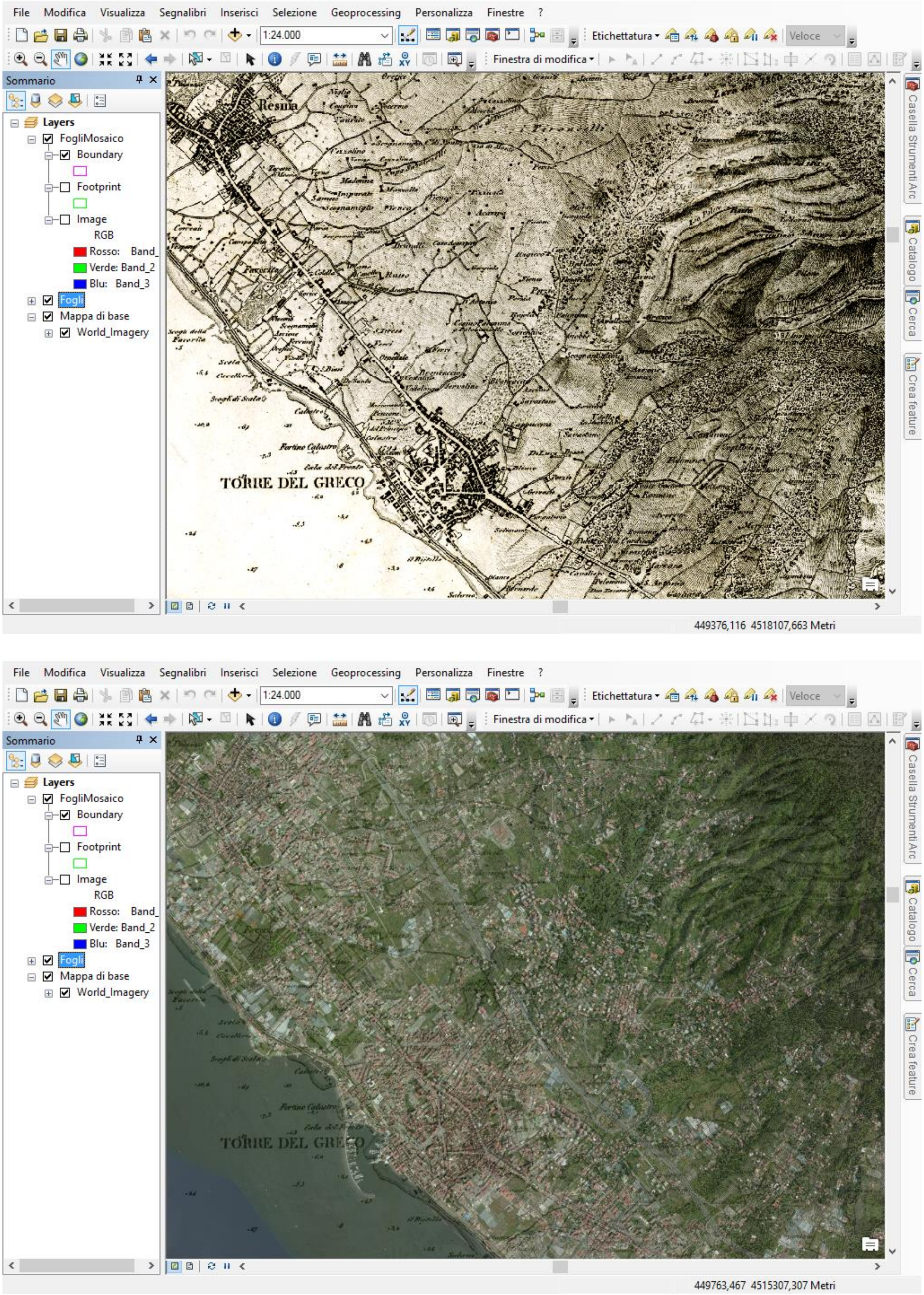
[4] By means of UAV systems it possible to produce rendering and DEM and compact pieces of high resolution orthophotos prior to the processing of precision digital cartography and the monitoring of particular phenomena of sensitive areas.

[5] See http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/21053-drs-03-2015.html (*Crisis management topic 3: Demonstration activity on large scale disasters and crisis management and resilience of EU external assets against major identified threats or causes of crisis*).





Figures 1 and 2. Above, a part of Sheet 9 of the "*Carta Topografica ed Idrografica dei contorni di Napoli levata per ordine di S.M. Ferdinando I Re del regno delle Due Sicilie dagli uffiziali dello Stato Maggiore e dall'ingegneri topografi negli anni 1817-1818-1819*" (updated to the 1862 Vesuvius crater). Below, the same image with an actual overlaying Basemap obtained by ArcGIS 10.3 with a transparency of 80% making it possible to observe and analyse the impressive differences recorded over a long period. Georeferenced and elaborated by D. Pavia and C. Pesaresi.



Figures 3 and 4. Above, a zoom on a part of Sheet 9, with the municipality of Torre del Greco highlighted, of the "*Carta Topografica ed Idrografica dei contorni di Napoli levata per ordine di S.M. Ferdinando I Re del regno delle Due Sicilie dagli uffiziali dello Stato Maggiore e dall'ingegneri topografi negli anni 1817-1818-1819*" (updated to the 1862 Vesuvius crater). Below, the same image with an actual overlaying Basemap obtained by ArcGIS 10.3 with a transparency of 80% permitting a highly detailed geographical analysis. Georeferenced and elaborated by D. Pavia and C. Pesaresi.

For example, in the preparedness and response phases, a powerful GIS platform, with which to combine, streamline, spread and share integrated sets of data and specific information on the local realities, structures and infrastructures involved, can play a central role in formulating and carrying out timely, well-coordinated and rigorously planned emergency steps, which are always characterised by urgent and critical decision-making activities, "in order to minimise further loss and effectively deploy relief" (Cova, 1999, p. 850). Moreover, again in the pillar "Societal Challenges", another topic referred to *Crisis management* underlines the importance of "an orchestrated set of actions, including standardisation. […]. Such standardisation activities could e.g. significantly improve the technical, procedural, operational and semantic interoperability of command, control and communication systems for crisis and disaster management, or the interoperability of detection equipment and tools"[6]. A sophisticated GIS platform able to profitably connect in a synergic way the benefits deriving from a large sample of geotechnologies and telecommunications, aimed at emergency management and field decision support, therefore becomes strategic also in terms of rescue operations, resource allocation, most suitable road networks and transport systems, survival time for entrapped occupants and consequent reduction of the fatalities (Béquignon and Soddu, 2005; Rasekh and Vafaeinezhad, 2012).

2. Some evidence and the new challenge

Different studies, for example the ones conducted in Japan, have underlined the added value that can be obtained by creating specific GIS portals, which can recover "great significance because it gathered various organizations from the national, local, educational, and private domains together and built a framework in which geographic information could be shared in real time to support disaster response activities", also permitting a rapid uploading and downloading of crucial data and avoiding – by the development of automatic, dialoguing and rigorous configurations – the risk of errors and miscalculation associated with manual data entry in dramatic and urgent situations (VV.AA., 2007a, p. 6).

At the same time, in the United States, the importance was highlighted of having "a GIS-based software program that estimates and maps the regional damage and losses resulting from an earthquake of a given location and intensity", since the "results support planning for natural hazards mitigation and response by state, regional, and local governments". In fact, "GIS is the ideal environment for earthquake loss modeling because it has the ability to analyse spatially distributed data such as demographics, the built environment, and infrastructure with a vast number of different attributes including quake magnitude, geological conditions, and structure type" thanks to a lot of spatial analysis functions and to the possibilities of converging in the different applications refined calculation models based on parameters and aspects selected together with the geographical provision (Corbley, 2007, pp. 16-17).

Similar GIS environments, opportunely calibrated according to rigorous methodologies, are able to "provide estimates of hazard-related damage before a disaster occurs", taking into account physical damage "to residential and commercial buildings, schools, critical facilities, and infrastructure", economic loss, i.e. "lost jobs, business interruptions, and repair and reconstruction costs", social impacts "such as requirements for shelters and medical aid". In this perspective, the system – where apposite earthquake models are previously defined – "can quantify the risk for a study area of any size, whether for a region, state, community, or neighborhood", providing "estimates of damage and loss to buildings, essential facilities, transportation and utility lifelines, and population based on scenario or probabilistic earthquakes" (VV.AA., 2007b, pp. 34-36).

So, "the challenge is to quickly gather data and accurately fuse it together to support emergency planners", creating a virtuous and "powerful mechanism available to emergency

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[6] See http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/21054-drs-06-2015.html (*Crisis management topic 6: Addressing standardisation opportunities in support of increasing disaster resilience*).

planners for collecting, storing, analyzing, and sharing the geospatial information needed by agencies to effectively support operations and restore disaster-affected communities in a relatively efficient manner", also with the aim to support critical decision-making both "before a disaster strikes and in the crucial early stages of disaster relief operations". Geospatial technologies can provide "vital" information such as locations of critical facilities and less resistant buildings, transportation routes and major areas affected by the catastrophic event and they can be very useful in every stage of the relief operations, as well cartographic bases and datasets where detailed and accurate, the models and methodology used are rigorous and the analyst well-trained and with interdisciplinary competences (Ware, 2007, p. 38).

The big bet is to predispose an "intelligent" system, a meticulously calibrated GIS platform from the geophysical and engineering point of view, streamlined with the geographic-humanistic and geomatics-statistical components, so as to perform in a number of points of absolute importance, which can be organised in a coordinated system among the various figures and bodies in charge of safety, risk management, emergency planning and civil protection operations.

The first point is to set up a dynamic reference database, not made up of excessive disorganised series of data, difficult to manage analytically and use in a concrete manner at short notice, but made up of concurring sets of accurate and vitally important data coming from multiple interfaceable sources. This database will contain selected uploaded data for digital cartographical processing and spatial multi-layer geostatistical analyses of varying complexity, aimed at pre-event simulation operations and the management of rescue operations and post-event phases.

A second point is to process and apply models and methodologies that are not characterised by mere automatic calculation processes, which at times for example lead to the spreading of data without taking due consideration of local factors, but in which the various algorithms, scenarios, simulations are the outcome of rigorous applications that take into account the real time parameters, the specific elements attaining to the area that has been hit, and the suitable recalibrations to be applied along the way.

A third point is to create a connection system among all the players and technologies used, from the central servers and dedicated software to the "mobile" devices given to the rescue teams and installed on the drones, which – should they be distributed in suitable focal points over the national territory, so as to reach the epicentres or the crater zones as soon as possible – would take the shape of crucial equipment to "photograph" the state of the overall damage, rapidly create a ranking of the intervention priorities on the basis of actual needs, detect the damage and impracticality of infrastructural networks necessary to reach more heavily hit zones, identify situations that could evolve and degenerate, reaching more critical levels in a short space of time.

Noteworthy must be the use of the drones, an essential element of the third point and a potential relevant innovative factor in the first phases post event, which can generate remarkable positive implications, permitting a very rapid recovery of detailed data and information in critical areas since strongly affected and difficult to reach (Thamm, Ludwig and Reuter, 2013). The use of remotely controlled drones makes it possible to avoid both the risks for the operators on the field and the clogging of roads, with an accurate and fast data collection, in wide zones, and – when the drones are well equipped – this holds true also during the night and in cases with scarce visibility too.

The drones – actually tested and used for scientific research able to study topography and show the geomorphological and physical characteristics which could be predisposed to future earthquakes and volcanic eruptions in virtual reconstruction 3D compacted by dedicated software[7] – can therefore acquire a role of

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[7] These studies, which involve a team of Italian and British researchers for specific reconstructions and analysis above all in exposed areas of Iceland and Greece, are coordinated by Alessandro Tibaldi (see for example http://www.geo-social.net/?p=829; http://www.unimib.it/open/news/Prevenire-i-terre-moti-con-i-droni-anti-sisma/4665975302505251605; http://www.rivistageomedia.it/en/tag/gps/feed/Page-3.html).

primary importance also in the first hours and days after the occurrence of a geodynamic event, with the aim of increasing human savability.

After all, there is a great amount of evidence which shows the importance of using UAVs, also in combination with satellite imagery and ground robots for collaborative mapping of an earthquake-damaged building (Michael et al., 2012) and on the basis of specific technical parameters for acquiring an increased level of autonomy allowing some phases of the process to be made automatic (How et al., 2009); and for the future the new added value may be related to the maximisation of the first-aid operations. Therefore, a stable and organic reference system, wherever it is possible to make detailed recordings and to upload data and documentation of different kinds, can be particularly important both as an immediate support and during the phases of decision-making and reconnaissance post event, aimed at damage relief, in turn preparatory for the restraint, consolidation and reconstruction of the ruined buildings and infrastructures in heavily stricken areas.

At the same time, the use of drones – as well as satellite-based methods and interferometric synthetic aperture radar – can be strategic before a volcanic event, for the measurements and analysis of volcanic gases (McGonigle et al., 2008), and during the eruption which, differently from an earthquake, is characterised by a slower temporal development. In similar situations, the use of drones, and also ground robots, can be fundamental to monitor the evolution of the eruption and the modification and advancement of the different phenomenology, overcoming the problems related to the conditions which foreclose the access to the crisis zones and near to the crater or the secondary mouths of the volcano. So, they can make it possible to acquire crucial information for the emergency management, representing "the future of cost-effective precision remote sensing" (Amici et al., 2013, p. 9) and a similar GIS platform, successfully dialoguing with each of its components, is highly functional also for the planning of operative phases, giving support in progress and defining synoptic frameworks.

3. The characteristics of the geolocalised integrated platform… towards the future

With its synergic development of last generation integrated geomatics techniques, engineering models based on probabilistic-statistical analysis techniques on available data and specifically derived implementing them in highly detailed geographic applications, the project aims to identify models of vulnerability and to make them directly useable, interrogable and interactive for the rescue teams in real time.

The forecast models of risk evaluation will represent the project support instrument for the ex-ante phase, becoming the exchange platform during the ex-post phase for immediately readable information. In fact the system should be organised like a real time geolocalised and geolocalisable database which makes it possible to coordinate the incoming information from the different aerial and land sensors and redistribute it to the single rescue teams, furthermore answering their progressive requests for more detailed information. At present the studies of the research group are directed at the formulation and validation of integrated geomatic models that return useful information for the evaluation of the parameters implemented in the vulnerability models (Baiocchi et al., 2012; Guarascio et al., 2007).

By way of example, the forecast model, already tested for the vulnerability estimate referred to seismic events, thus makes it possible to express in a comparative way the expected behaviour of the buildings representative of the different types of construction present over the area. In the analysis carried out, it could be seen how buildings that were similar in construction features, height, year of construction and positon in the construction aggregate, built on analogous geolitological substrata, suffer significantly different damage if subject to the same stress. The causes of this different behaviour can be identified through the increasingly detailed analysis of the construction features and the elements around the buildings themselves. The ad hoc gathering of more detailed information, adopted as variables of the forecast model, is justifiable only if the costs-benefits analysis gives back a positive evaluation in terms of an increase in savability.

The vulnerability model generates the “ex-ante rating” on the potential damage caused by the natural disaster, thus giving the operational guidelines that make it possible to efficiently coordinate survey systems of Mobile Mapping Systems and drones (UAVs; Figure 5), equipped with measurement instruments (thermal cameras, telecameras, laserscanners etc.), used for the ex-post identification of the actual damage and the real time return of the “ex-post rating” for the planning of emergency and rescue operations. The operators of the emergency teams could with simple commands from a screen ask for further surveys of areas of specific interest, interactively updating the vulnerability map in this way and permitting the improvement of the priority estimates in an interactive process leading to the optimum streamlining of the rescue operations. The modern UAVs allow a complete and continuous image flow from the sensors installed on the drones to the operators and the master control centre (Boccardo et al., 2015): what has to be absolutely preserved is the integrity of the network connection and for this reason specific backup infrastructures need to be present on the site.

This system is within the present technical possibilities and engineering design, as demonstrated in some examples (Baglioni et al., 2013; D’Orazio et al., 2014): also data that can be recovered simply and rapidly can significantly improve the decision-making process. The evaluation of the integrity and reliability of the communications network is the functional assumption of the emergency management model which, if properly applied, streamlines the rescue operations.

It is strategically important to bear in mind that the system must be implemented and integrated in the very first alert phase for the risk event and that such phase must be aimed at organising and coordinating as much georefereable information as is available on the area and its features.

The management of the very first emergency phase is of vital importance for human savability, and the streamlining of a completely automated management procedure of the teams will make it possible to save time that is never as precious as in that specific phase, as the recent experience in L’Aquila teaches us (Grimaz, 2011) and, above all, di Haiti (Ajmar et al., 2013; Kapucu, 2015).

In detail the system should develop in the following steps, considering that many of the passages are not unidirectional but must be taken iteratively so as to streamline and calibrate its parameters, making it possible to reach a higher and higher level of reliability.

- Setting up of a relational georeferenced database containing all the data available for the assessment and estimate of the risk parameters, vulnerability and dangerousness, referred to the specific emergency and to those likely to be triggered by the event itself, like for example what happened for the Fukujima disaster[8].
- Implementation of the communications network between the central database (opportunely duplicated by means of “mirroring” systems) and the single input and output devices and verification of its robustness also in the case of extreme emergency (total loss of electricity, total collapse of the existing mobile data infrastructure).
- Planning of the scale of priorities of the remote testing and inspections to be carried out in real time by the remotely controlled sensors (mainly drones, Figure 6) and testing of their continuous database updating capacity.
- Study of the interface and its legibility by the rescue team, verification of the modalities of the detailed requests by the single teams, verification of the intuitiveness of the interface, verification of the functionality, consistency and robustness.
- Prioritisation criteria of interventions to be communicated in real time to the individual teams according to: ex-ante data, “automatic” tests by the remote mobile sensors, ad hoc verifications requested by the teams.
- Exclusion of the single site from the list of priorities at the end of the intervention for the first safety measures carried out by the team.

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[8] See for example Nishikawa et al., in press.

- Communication of the end of the state of emergency upon termination of the last safety intervention on the last site.

The integration of these technologies, algorithms and the necessary calculation models requires the development of specific strategies that are both calibrated for each single event and contextualised in automatic processes, but the benefits in terms of predictable savability are so high as to "repay" the efforts and create the premises to "assemble" a structured pilot geotechnological system based on the synergy between the geomatics, engineering and geographic points of view. All this is with a view to moving towards a collaborative emergency management system where different research fields and levels of government and institutions "come together to address a common goal and produce shared results" (Kapucu, 2012, p. S41) finalised to social utility in case of geodynamic events.

Figure 5. Octocopter used in a real post-seismic scenario. Photo: M. Mormile (2015).

Figure 6. Quadcopter during the surveying of a facade during a post-seismic phase. Photo: M. Mormile (2015).

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Acknowledgements

V. Baiocchi wrote paragraph 3; C. Pesaresi wrote paragraphs 1 and 2.

The Authors thank Prof. Roberto Scandone for his very useful comments and suggestions.

The Scientific responsible for the GIS4RISKS project, financed by the Sapienza University of Rome, is Cristiano Pesaresi.

The Institutions which have expressed their interest to participate in the GIS4RISKS project are the following: The Italian Civil Protection Department (Presidency of the Council of Ministers) – Office III: Seismic and Volcanic Risk; The National Institute of Geophysics and Volcanology (INGV); The Environmental Systems Research Institute (ESRI Italia); The European Space Agency (ESA/ESRIN); The Geographic Research and Application Laboratory (GREAL) – European University of Rome; The Italian Association of Geography Teachers (AIIG).

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