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Sharing the post-earthquake situation for emergency response management in transborder areas: The e-Atlas tool

Stefano Grimaz*, Petra Malisan, Andrea Pividori

SPRINT-Lab, Polytechnic Department of Engineering and Architecture, University of Udine, 33100, Udine, Italy

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ABSTRACT

Usually, the response after a disastrous event requires decision-makers in emergency operative rooms to quickly outline and understand the current post-event situation, for planning and defining strategies for a contextualized response. Moreover, in many cases, disastrous events affect cross-border territories and/or involve multiple organizations in responding to the demand generated by the event. These cases require a harmonized and coordinated response by all the institutions/subjects involved in emergency management. To address this challenge, this paper proposes the e-Atlas (emergency atlas) tool for showing and sharing information that embraces a response management perspective to explicitly support decision-makers in managing the criticalities of a post-earthquake situation. The e-Atlas has been designed and tested to: i) acquire sensible information for allowing decision-makers to understand in almost real-time the post-earthquake situational picture, and ii) share the representation of the situational picture among different users, allowing each of them to use it according to its specific requirements. Applications of the tool are illustrated, to show how it is used in a transborder context in the North-East area of Italy.

1. Introduction

Immediately after a disastrous event, decision-makers involved in the emergency management process (EMP) are called to deal with and manage the post-event situation with the definition and establishment of actions for providing a prompt and suitable response to face and remove criticalities, and to facilitate the achievement of a “new normality” as soon as possible. In this context, decision-makers need to take into consideration that disasters represent a complex set of problems, that could quickly evolve or also drastically change both with time and depending on different zones [1]. For this reason, the management of an emergency after a disaster requires decision-makers to define effective and efficient actions and interventions in a short time, for reducing the impact of the adverse event and minimizing its effects [2]. For this purpose, the subjects involved in the response need information for understanding the substantial features of the post-event situation and consequently take adequate and sound decisions [3]. The information acquired to represent the situation should satisfy as better as possible the “dimensions of quality information”, i.e., being available, reliable and relevant [4]. Considering these aspects, what decision-makers require is an overall and up-to-date view of the post-event situation, available in a short time window. This view should provide them with the essential information, without the need to analyse and evaluate technical details and extended documentation during the already delicate phase of response [5]. For decision-making, having too much information available could be a counterproductive strategy, which can potentially lead to a chaotic situation: without careful selection and prior categorization of data, it could be difficult to identify quickly the essential aspects for prompt response [6,7]. In this context, reducing the response times is essential and this can also be achieved by pre-selecting the substantial information in “peacetime” (i.e., before an adverse event). The preselection should consider who the end-users are and what their needs are, to simplify and make information more effective to use. Decision-support information should therefore be acquired, processed, and made available immediately after an event, according to predefined and pre-coded procedures. To this end, it is necessary to design suitable tools for acquiring, processing and representing information, as well as to finalize the representation of the results considering the needs of specific users, for enabling them to define emergency actions [8].

Usually, after a disastrous event, the activation of disaster management structures entails the involvement of decision-makers with different functions and perspectives (such as emergency services managers, and representatives of local authorities), which should consider the whole context of the situation before outlining an action plan for the response. For this purpose, decision-makers are called to initiate, coordinate and monitor the implementation of all measures intended to address and cope with the disastrous situation, seeking for the minimization of the effects of the adverse event. According to Fogli and Guida

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* Corresponding author.
E-mail addresses: stefano.grimaz@uniud.it (S. Grimaz), petra.malisan@uniud.it (P. Malisan), andrea.pividori@uniud.it (A. Pividori).

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[7], the usability of a decision-support system relies on a clear selection of base concepts and on its ability to model any type of situation. In Italy, the management and planning of emergencies are entrusted to the Civil Protection, which is organized in different administrative levels, and regional, provincial, and local structures. Civil Protection has to face complex emergencies, and it adopts a standardized and easy to implement approach, named "Augustus method". The Augustus method is currently used as a guideline for the creation of emergency coordination centres at all levels of Civil Protection, from local to national [9]. In fact, in Italy, at a regional level, different Civil Protection organizational structures exist, and a common method is required for coping with emergency situations.

Moreover, it should be considered that disasters can involve different regions or nations, and such events may require a coordinated management by various institutions of different countries, which may adopt different and distinguished protocols and procedures. Cross-border emergencies can become more intense considering geographical and functional boundaries, and their combination can also lead to an increase in the catastrophic potential [10]. The growing frequency, intensity, and duration of cross-border disasters, together with the ability to manage cross-border emergencies and crises are raising concerns, also considering the implications of the growing impacts of climate change [10,11]. The possibility of transnational emergencies implies the potential involvement of various civil protection systems, which may have significantly different operational procedures; anyhow, for cross-border emergencies, they are required to cooperate, and therefore to establish a coordinated approach for disaster management [12,13,14]. In this context, and especially when dealing with complex situations, information sharing is essential to improve the response efficacy and quality, and at the same time, to develop the resilience of the system [15]. This is the case of large earthquakes in transborder areas, such as the area between North-East of Italy, South of Austria, and North-West of Slovenia. This area has been subject to strong seismic activity, proved by large earthquakes occurred in the past, such as the 1348 Carinthia earthquake (estimated M_W=6.6), the 1511 Slovenia earthquake (estimated M_W=6.3) and the 1976 Friuli earthquakes (M_W=6.5) (from the catalogue of strong earthquakes in Italy and in the Mediterranean area [16]), and smaller earthquakes occurred recently, such as Bovec-Slovenia earthquakes in 1998, M_L=5.5 and in 2004, M_L=5.2 [17]. These events highlight the importance of transborder cooperation for the management of disasters, and various projects have been developed to strengthen the cross-boundary cooperation [18,19]

It follows that an effective response to a cross-border disaster relies on a well-organized, harmonized and coordinated response of all the actors involved in EMP (such as decision-makers, technicians, civil protection operators). As discussed by Bjerge et al. [20], in the immediate aftermath of a disaster, the exchange of relevant information among stakeholders is critical, and various platforms exists to support these efforts (see, [20,21]). The sharing of relevant information is strongly supported by a common and shared situational picture of the post-event situation, based on geographic information, that is represented according to coordinated and harmonized rules and conventions designed and tested during the preparedness phase. Geographic Information Systems (GIS) has proved to be an optimal tool to answer the needs of creating common representations (e.g., atlases) of the post-event situation, allowing to implement an effective and rapid system for collecting, representing and sharing the information among various subjects referring to different emergency management operative rooms [22,23,24,25,26]. As examples, there are the Virtual OSOCC (On-Site Operations Coordination Centre [20]) which is a part of the Global Disaster Alert and Coordination System (GDACS) under the United Nations Office for Coordination of Humanitarian Affairs (UN OCHA), and the Copernicus Emergency Management Service [27] that is implemented in Europe. The map component of Copernicus provides mainly Civil Protection Authorities and Humanitarian Aid Agencies with geo-spatial information derived from satellite remote sensing. The information, depending on the required outcome, is available starting from few hours after the events, or it could require some days of elaboration.

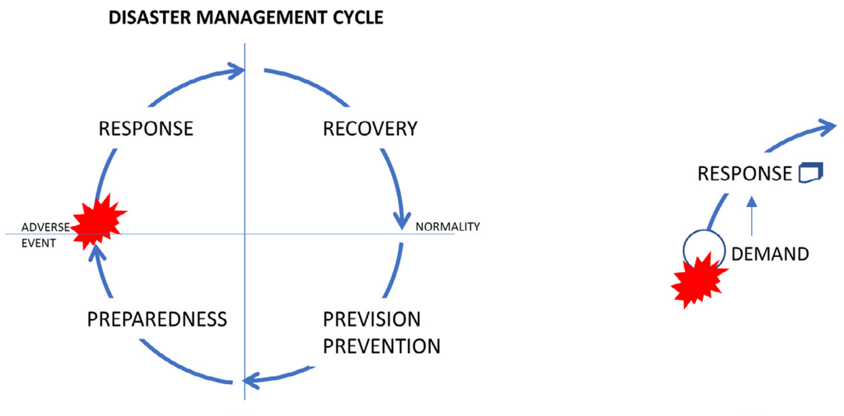
The above considerations highlight the strategic importance of a shared tool for monitoring and assessing the post-event situation for emergency response management purposes in transborder areas. This tool should allow decision-makers to outline and understand the characteristics and peculiarities of the situation and its evolution, as well as of the associated demand, and to consequently establish sound response strategies.

This paper firstly illustrates the conceptualization of the process adopted by decision-makers, when they need to outline and understand the post-event situation and its evolution, for planning and establishing response strategies. This process is used as the conceptual framework for the definition and creation of a tool (in detail an atlas) for supporting decision-makers in the above-described contexts and specifically tailored to post-earthquake situations. Finally, the paper illustrates how the conceptual framework is applied to create an emergency atlas (e-Atlas) for the post-earthquake management of the regions of the Italian North-East area, characterized by a moderate-high seismic hazard and by the fact of being a cross-border area, with Austria and Slovenia. This e-Atlas is implemented in the Civil Protection operational room of the Friuli Venezia Giulia Region (NE of Italy) as part of the INTERREG Italy-Austria ARMONIA project, which aimed to develop transnational strategies for the management of natural disasters.

2. Conceptualization of the post-event process from demand to response

Disaster management disciplines deal with all activities aimed at managing emergencies, carried out both in preparation for an adverse event and after it. According to the United Nation Office for Disaster Risk Reduction (UNDRR), disaster management has the purpose to reduce or avoid potential losses caused by adverse events, ensuring timely and adequate assistance to victims, and obtaining a quick and effective recovery [28]. Fig. 1 (a) schematizes the main phases of the disaster management cycle. These phases are commonly used to divide the disaster management process, and to contextualize the plans and actions aimed at reducing the impact of disasters [29]. The disaster management cycle shows that after an adverse event there is the response phase, which aims at managing the post-event situation trying to stabilize it and saving victims. However, in this phase, it is necessary to outline the situation and understand the demand of needs arose from the post-event situation (Fig. 1 (b)): this will permit to identify, plan and implement the actions of the response phase. The recovery phase follows, aimed at defining and implementing actions for returning to the "normality". The prevision and prevention phase (also known as "mitigation") focuses on actions to prevent or reduce ex-ante the causes, impacts and consequences of a disaster, while the preparedness phase aims at developing activities, planning and training to be prepared for facing the next adverse events. In the management of a disaster, the characteristics (in terms of duration and magnitude) of the adverse event play an important role especially in driving the response phase. In the seismic case, the event is almost immediate with no or very short early-warning, and it is commonly followed by other events occurring in almost the same area, with usually a lower magnitude (aftershocks).

To realize the importance of understanding the demand within the response phase, it is fundamental to consider that, generally, characterize disasters are complex and extensive. To address these types of problems, Wagner [30] divided the managerial problem-solving process into four phases: 1) problem analysis, 2) identification of the appropriate solution, 3) implementation of the solution, and 4) achievement of objectives. During an emergency following an adverse event, the managerial problem-solving process can be considered as a process that aims to transform an initial critical situation (current situation) into the desired situation, in which dangerous issues are removed or kept under control (Fig. 2). The transition from the current situation to the desired one



(a) (b)

Fig. 1. (a) Disaster management cycle; (b) A contextualized response after a disastrous event is based on the rapid understanding of the demand generated by the event.

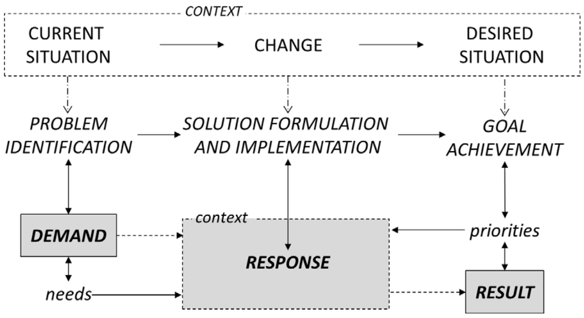


Fig. 2. Framework for the description of the demand-response-result relation.

is identified as a "change", and response activities allow to formulate and implement solutions, to provide a response to the identified problems for the current situation. It should be noted that the whole process is part of a non-ordinary context; hence, the solution needs to be contextualized, considering boundary conditions such as critical situations, limited time, and available resources. In this framework, the solution can be considered as the response to a need for change, therefore, as a first step, it requires having effectively identified and characterized the problem in terms of demand.

Fig. 3 shows the passages from understanding the demand to defining the response after an adverse event. Understanding the demand implies the need to maximize and optimize the ability to read and interpret the situation, outlining the problems, identifying and taking into account the causes that generated them, and the conditions that characterize the context. This has to be done while minimizing the time spent for understanding the demand, i.e., trying to optimize effectiveness. Similarly, when responding to the demand, it is important to maximize the effectiveness and the contextualization of the response, considering the context boundaries that characterize the situation. The formulation and implementation of the response should also be developed trying to minimize the time, to provide prompt relief to the population, to remove or minimize problems and eventually to stop or manage the evolution of the critical situation.

To understand the demand, it is necessary to understand "what, where and why", concerning the following aspects of the situation (Fig. 3):

- **critical issues**, identifying which are the critical situations, where they are located, and why they arose;
- **needs**, outlining what the needs are (in terms of required interventions and resources), where they are mostly requested, and why;
- **constraints**, determining and characterizing what constraints exist in the context, that can limit the adoption and execution of certain response countermeasures;
- **priorities**, analysing if there is a need to prioritize some response actions, and evaluating which actions should be prioritized, where, and why.

This information supports decision-makers in the definition of the response actions, i.e., of the countermeasures to be implemented for providing solutions to the problems. The definition of the countermeasures for responding to the demand should take into consideration:

- who is involved in planning, considering the subjects of potentially various organizations that should cooperate and collaborate, that could come also from various countries;
- how to implement the countermeasures in the identified context, taking into account the constraints;
- when to perform the countermeasures, according to the established priorities and the availability of resources.

Starting from the knowledge of this basic information, decision-makers can define the actions to respond to the demand, contextualizing the proposed solutions and maximizing their effectiveness.

The challenge of functionally organizing the information arises, and should be addressed in the preparedness phase to simplify and optimize the management of the post-event situation. A strategy for optimizing the demand-response process is to pre-codify both the expected demands and the associated responses (Fig. 4(a) and (b)). This should be done by each subject (e.g., organization, institution) involved in the EMP. If demands and associated responses are pre-codified, after an event, decision-makers tasks would be to recognize the current demand among those pre-codified (if possible), and identify and manage the associated response. This would reduce the tasks of decision-makers in a crucial moment when the majority of efforts should be devoted to the identification and application of the response action plans.

The pre-codification of demands and responses should be developed during the preparedness phase, when decision-makers, technicians and operators working in emergency management operative rooms or situational rooms are called to elicit, collect, analyse, and summarize the information useful for the pre-codification of the demands and associated response. In detail, they should contribute by:

- providing knowledge of the environment in which each subject works, specifying capabilities, constraints, procedures, etc.;
- giving information and knowledge about the resources that can be mobilized, considering also eventual limits (and the potential need to increase specific resources), and procedures for the mobilization,

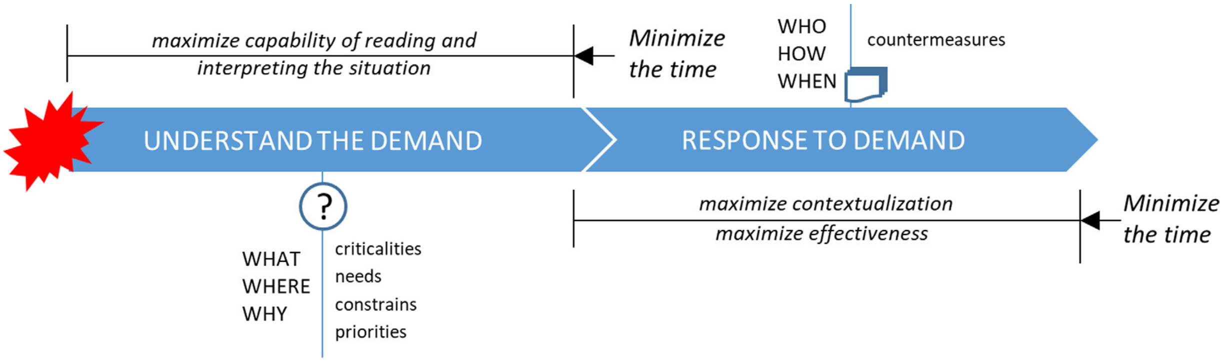
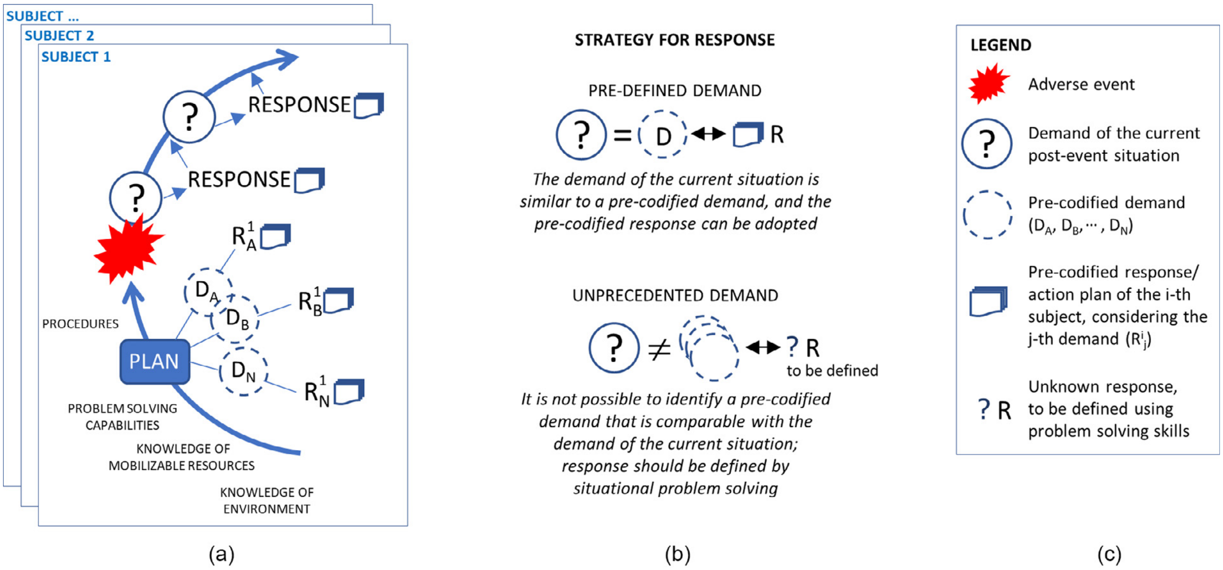


Fig. 3. After an adverse event, it is necessary to understand the demand to outline the response (demand-response process).



(a) (b) (c)

Fig. 4. (a) Pre-planning of pre-codified demands and responses in the preparedness phase to improve the response phase, and each subject involved in the emergency management develops its responses, that should anyhow be coordinated with other subjects; (b) Strategies for response identification in the case of pre-defined demand (top) or unprecedented demand (bottom); (c) Legend of the symbology used in subfigures a) and b).

as well as creating connections with other subjects to simplify the coordination during the emergency management;
- developing problem-solving capabilities, which will be essential during emergency management. Problem-solving capabilities can be developed also during the management of real emergencies, or through exercises.

The above-described knowledge and information should be used to define plans for facilitating the response phase, by pre-codifying both potential demands and responses. Fig. 4 (a) shows how each subject (e.g. subject “i”) associates its own pre-codified responses (e.g., R^i_A, R^i_B, ⋯, R^i_N) to the pre-codified potential demands (e.g., D_A, D_B, ⋯, D_N), which are common for all subjects. After an adverse event, the understanding of the current demand will allow decision-makers to compare the recognized demand with the pre-codified ones, permitting the identification of two main lines of strategies for the response (Fig. 4 (b), starting from the following aspects.

- A pre-defined demand: if the recognized demand is similar to a pre-codified demand, then decision-makers can adopt the response that has already been associated with the demand (this strategy is generally adopted for emergency management, when there are pre-assesses responses to the situation).
- An unprecedented demand: if it is not possible to relate the current demand to the pre-codified ones, then the response has to be defined, taking advantage (if possible) of the problem-solving capabilities developed during the preparedness phases; the problem-solving skills allow, through creativity, contextualization, improvisation, etc. to identify and propose actions to mitigate the consequences of the problem (this strategy is generally adopted for crises management when there is not a pre-assessed response to the situation).

During the response phase, the situation and the demand should be continuously monitored to check if and how they evolve, and this has two main purposes: a) to check if the implemented countermeasures are effective and/or if there is the need for adjustments, and b) to check the situation and monitor its evolution, especially in the case a further adverse event occurs (and this is a very common situation in the case of earthquakes), but also the check changes after the implementation of response actions.

In addition, it must be considered that the response to the demand is generally provided by multiple subjects called to work for responding effectively to the demand created by the event, and this implies the need to share a common view of the post-event situation. In a cross-border scenario, the response typically involves organizations from different nations, having usually very different organizational and response schemes and procedures. As previously described, in the transborder area between Italy, Austria and Slovenia, large earthquakes could occur, involving the local Civil Protection system of the three countries. However, the three local Civil Protection systems are organized differently starting, for example, from the level of organization, which can be

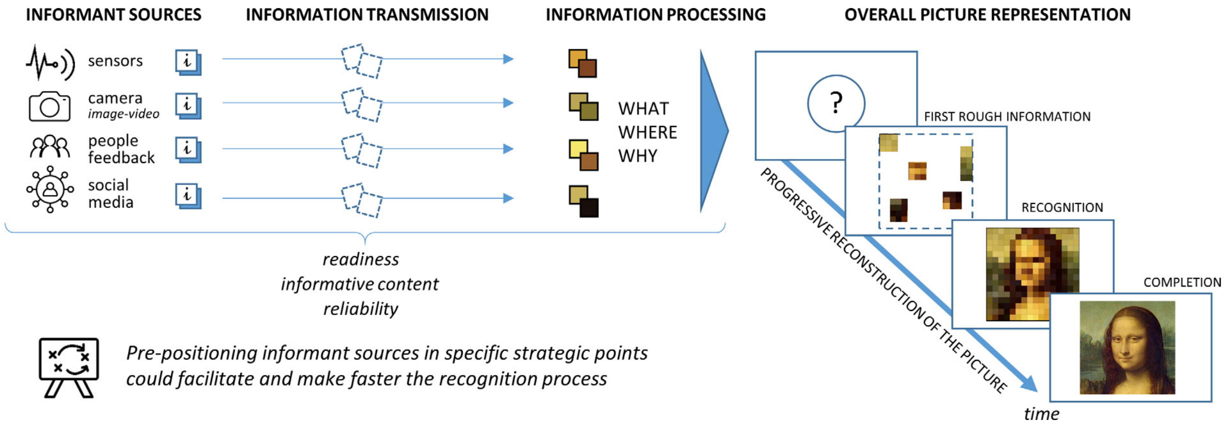


Fig. 5. Use of the informant sources for the progressive reconstruction of the situational picture (painting metaphor).

at Country/Regional, District, or Municipality level. Specific collaborative protocols already exist between the Civil Protection systems, but it is essential that the various stakeholders share a common information on the situation to cope with the response phase. This aspect underlines the necessity to outline a common representation of the post-event situation, that should be shared among decision-makers in almost real-time and using a common "language" that should be arranged during the preparedness phase.

During the preparedness phase, it is therefore essential to finalize procedures and tools for supporting decision-making and action-plan establishment in responding to emergency demands. This implies the necessity to define a tool for rapidly outlining the post-event situation and understanding the demand.

Outlining the post-event situation is therefore the fundamental step of the demand-response process. For this purpose, it is essential to gather specific information from informant sources, which provide relevant information on the post-event situation for certain points or areas. Both informant sources and the elements of the information to acquire should be pre-identified during the preparedness phase so that they can be acquired when necessary (Fig. 5). The informant sources can be classified according to the following main categories.

- Technological devices, they can be:
  - ○ sensors, for the acquisition of measured data concerning the event and its effects (e.g., seismometers, accelerometers, tiltmeters);
  - ○ cameras (fixed or mobile) for the acquisition of images concerning the situation (e.g., drone cameras, satellite cameras, laser scanners, thermal and infrared cameras).
- Human, they can be subdivided considering:
  - ○ on-site people feedback: generic feedback can be used, but it is also possible to train local volunteer surveyors, which will acquire information according to pre-defined and shared methodologies;
  - ○ social media reports, for generic and widespread information on the situation, without the need of having specific personnel training.

The information of informant sources is useful when it is transmitted to and collected by a specific tool for the situation representation, that should also allow for further processing to obtain a progressive reconstruction of the situational picture. The situational picture outlines the post-event situation for emergency management by decision-makers, technicians, and operators through a representation that is functional for understanding the demand.

The availability, readiness, reliability, and meaningfulness of the information are fundamental for outlining the situational picture through the steps of information gathering, processing, and sharing. Moreover, to answer to rapidity and efficacy requirements, the situational pictures are outlined and sharpened according to a progressive reconstruction approach in time (Fig. 5). The information processing should take into consideration: what information should be collected, where the informant sources are, and to what extent (why) their information contributes to the reconstruction of the picture.

The right part of Fig. 5 shows an example of progressive reconstruction using a painting as a metaphor. The progressive reconstruction begins from a completely unknown situational picture, followed by a first rude reconstruction built using the first rough information that allows to point out the substantial features. Gradually, the reconstruction is improved using the increasing amount of information, allowing for a more in-depth recognition of the situational picture, eventually up to the complete reconstruction of the picture. However, it is not always necessary to guarantee a complete detailed level of representation, also because the situation could rapidly evolve, and the detailed representation could be useless, being not more representative of the current situation. In such contexts, seeking for a complete and detailed representation could be even counter-productive, because it would move the attention of decision-makers from outlining and understanding the whole situation to endeavour for a detailed representation that could be representative of the post-event situation only for a short time. Anyhow, decision-makers could need a detailed representation of some specific aspects or for some areas, according to specific requirements, and depending on context and current situation. This idea highlights that the most important level of reconstruction of the situational picture is recognition. As a practical example, we refer to the case of the seismic emergency management in Central Italy in 2016, when, after the seismic event of the 24 August 2016 (M_W=6.0), the damage of buildings was assessed starting with a first triage assessment aimed at providing an overview of the situation [31], and not with a detailed assessment of the damage of each building. The suitability of this approach was proved when the earthquake of the 30th of October 2016 (M_W=6.5) occurred in the same area, drastically changing the situation and the demand, requiring, therefore, decision-makers to re-assess the current situation for establishing new response action plans.

The progressive approach to the problem highlights the importance of having identified the informative sources and having set up the entire system during the preparedness phase. With reference to the example of progressive reconstruction of the picture, it is important to have an idea of the salient elements of information (substantial information) that permit to draft the situational picture, to arrange the informative sources for responding to these needs. The information to use for the representation of the situational scenarios considers both the type of information and the location of sources. Additional information is used to improve and refine the understanding of the demand and eventually to have a dynamic focus of some specific parts of the situational picture.

According to this approach, it is possible to analyse the post-event situation from multiple perspectives and with various purposes; for each of these points of view, it is possible to create a different representation of the situation. This led the authors to develop the idea of collecting all these pre-codified functional representations of the situation in a sort of atlas, that becomes a tool for supporting decision-makers in analysing and understanding the demand considering different thematic aspects. The atlas becomes therefore a tool for collecting, mapping, and sharing the information, and also to systematize the information that could arrive from various sources. When various and different subjects both concur to the definition and share the utilization of a common atlas, particular attention should be given to harmonizing how information is collected and to establishing a common representation of the outcomes.

3. e-Atlas: a tool for outlining the post-earthquake situation

This section illustrates the e-Atlas as a tool for applying the conceptual framework previously illustrated and answering the issues that arose, considering a post-earthquake situation. The key questions at the base of the organization of the e-Atlas are: what types of information should and could be acquired? How to gather the information? How to use the information to outline the situational pictures? Moreover, the e-Atlas should allow for a progressive reconstruction of the situational picture, the sharing among various subjects and the need to monitor the continuous evolution of the situation, both as a consequence of the implementation of the countermeasures and as the potential effect of further adverse events, which, in the seismic case, are aftershocks or other main-shocks, as usually occur in seismic areas [32].

As already observed, the e-Atlas has to be set up during the preparedness phase, identifying the substantial information that will allow representing the situational picture, and the related informant sources.

Atlases are commonly created through GIS applications, computer-based tools that provide the ability to acquire, analyse and visualize spatial and non-spatial data. Furthermore, the GIS allows to query the maps, to quickly overlay the represented information, and also to develop further evaluations using the georeferenced data to obtain results of interest. The needs of decision-makers indicate the requirement to have a tool that exploits the adaptability, modularity and querying capability of GIS and the pre-coding and subdivision of information into specific thematic maps, as well as the collection of these maps according to a pre-defined structure typical of an atlas. In this way, it is possible to collect data with different contents, coming from various subjects, and harmonize them using the GIS potential through data processing according to specific algorithms.

An important point to consider while developing the e-Atlas is the possibility of gathering contributions from different information sources, often belonging to different subjects. In the case of earthquake events, for example, there could be seismic networks managed by different organizations, and this could happen both when networks are in different countries, or in the same country. The more different subject, organizations, and institutions are involved in providing data, the more it will be possible to identify useful contributions to improve the level of detail of the representation. In this context, however, it could be necessary to reasonably skim information sources to acquire and represent mainly those functional to the delineation of the situational picture, avoiding the collection of data that does not contribute to the purposes of the e-Atlas. The e-Atlas, therefore, acts as a filter, collector, and viewer of information from various contributors, concerning both the information relating to what happened following an event (coming from informant sources), and also basic data and information, collected and catalogued before the event, such as the geographical or administrative maps of the areas, or maps referring to the system of informative sources.

The basic and event-informative data and maps are acquired and catalogued in a database, which can also be further populated by processing and analysing the acquired information. The data collected in this way are represented in GIS layers, while the functional grouping of layers allows defining the thematic maps of the e-Atlas. This approach allows the creation of a collective system, to be used in EMP.

Subsequently, decision-makers need to analyse the situational pictures through a representation that could be declined on the basis of specific needs depending on the user, and which purposes are to outline the situation, understand the demand and identify the responses. The layers and thematic maps of the e-Atlas can therefore be freely used by each of the decision-makers to define specific views for representing and summarising the post-event situation according to specific requirements. These views allow decision-makers to better outline the demand and plan the response. To support decision-makers and harmonize the e-Atlas, layers and thematic maps should adopt an easy-to-understand symbology, representative of the information content, and as uniform as possible, both considering the significance and the need for use by different users [33]. Symbols and legends, defined and adapted according to the needs of the e-Atlas, are shared among all the involved subjects.

With reference to the above-described conceptual schemes and requirements, the three following steps illustrate the process at the base for the development of the e-Atlas for representing the post-earthquake situation: 1) identification of informant sources and information gathering; 2) data cataloguing and processing; 3) representation of thematic maps and views. These steps are arranged during the preparedness phase and implemented after every adverse event. In the case of a seismic sequence, the phases are automatically repeated after each seismic event with a magnitude above a pre-defined threshold.

3.1. *Identification of informant sources and information gathering*

At the basis of the whole e-Atlas tool, there is the information gathered from the informative sources. It must be acquired, transmitted and collected in a suitable database. Information is distinguished considering if it is (or not) informative of the specific adverse event; therefore, it is possible to identify “base data”, which are acquired usually before the event, and “event-informative data”, collected after an event and whose content is informative of the post-event situation. Base data concern mainly geographic and administrative contents, which should be maintained up to date. Event-informative data gathering starts immediately after an earthquake and this process should be performed in the shortest time possible.

The data of the informant sources can be used either to characterize a point in the map (as it can happen for the information measured in the pre-identified buildings, hereinafter called sentinel buildings) or can characterize an area (such as the feedback from citizens or civil protection volunteers of specific municipalities). It is also possible to use punctual data to make evaluations for an area around the source point (called buffer area), given that it is possible to spread the acquired information as representative for the area.

Based on the previous considerations, the following informant sources (either punctual or spatial) should be considered to delineate the e-Atlas for post-earthquake situations:

- Cartographic and administrative data: these data provide information on the main characteristics of the area potentially affected by the adverse event (e.g., built areas, topography, geomorphology, administrative boundaries, protected areas).
- Census data: these data provide spatial information on some characteristics of the areas analysed in the e-Atlas (e.g., typologies of facilities, building structural typologies, main geometric features of buildings). Census data are usually divulged in an aggregated view, with a summary of the information for specific zones.
- Seismic ground motion sensors: seismic sensors (usually accelerometers or seismometers) acquire the seismic ground motion in specific informative points, and this permits the calculation of the parameters about the seismic intensity. The location of the seismic sensors has been established to cover mostly the areas with larger seismic

hazard, and to allow evaluating the seismic ground motion in free field, in an urban context and also in sentinel buildings previously assessed. In detail:

  - ○ Seismic sensors for the measure of the ground motion: these sensors provide real-time information regarding the actual ground shaking, measured in different points of the area of interest. Nowadays, free-field seismic monitoring stations are increasingly widespread, and they are generally more or less dense depending on the seismic hazard. Usually, temporary seismic networks are further installed following a seismic event [34]. The geomorphological characteristics of the seismic stations [35] are associated with the stations, and this information must be acquired together with the position of the sensors. Generally, the sensors of the seismic networks are positioned in free-field, but sometimes they are located inside urban centres, where the seismic motion can be modified by the interaction effect between site and buildings [36].
  - ○ Seismic sensors in buildings: the seismic shaking can also be recorded through sensors positioned inside specific buildings. The sensor can be placed in different positions in the building, depending on the purposes of the interpretation of the recorded data. If seismic sensors are installed on the upper floors of a building, it is possible to use the recorded seismic shaking to directly check how the structure behaved during the seismic event [37,38,39].
- Photos and videos from cameras: quick feedback of the actual post-event situation comes in a short time from photos and videos acquired in the affected territory. However, in order to use this information in the e-Atlas, it needs to be further processed, often requiring a long time. Drones and helicopters can provide an aerial view, or it is possible to have satellite images of the affected areas. However, the availability of these images usually requires some time both for acquiring data and for georeferencing them; moreover, their availability depends on weather conditions.
- On-site people feedback: the feedback of persons in the affected area can be used as a source of information on the situation. The on-site feedback can come either from experts, trained, or non-trained persons. Experts and trained persons will provide information according to pre-codified rules and in a structured way, and this information will contribute to generating pre-defined maps of the e-Atlas. Similarly, it is possible to prepare one or more maps using feedbacks that people provide for other purposes, such as, during calls to the emergency system for assistance.
- Social media feedback: after a seismic event, much information comes directly from the population that felt the earthquake (via social media such as Facebook, Twitter). There are numerous methodologies (see [40,41] and references therein) that exploit crowdsourcing for emergency information management, i.e., the acquisition of information from many people, generally shared via the internet.

The structure of the e-Atlas allows for dynamic focuses in different areas, depending on either informant sources availability, and the characteristics of the areas. This is particularly important when different territories (and, in the case of cross-border events, different countries) have distinct typologies of administrative data or seismic monitoring networks. As a consequence, there could be different levels of monitoring of the situation, also depending on the various organization of the institutions contributing to the e-Atlas.

3.2. Data cataloguing and processing

The information acquired and collected in the e-Atlas database should be catalogued functionally in thematic groups for easier use by operators and for allowing, if necessary, to retrieve historical information concerning past events.

The data gathered from the informative sources are represented in GIS layers, which can collect and represent the data as they are acquired from the information sources or after being processed according to more or less complex algorithms. To organize the layers in the e-Atlas, they are catalogued by functional groups, which are useful for the organization and management of the database. Furthermore, the layers are used for the definition of thematic maps, which are representations for outlining the situational picture for decision-making purposes. To this end, the informative contents of the various layers are processed and possibly combined according to algorithms defined for each thematic map. Moreover, in each thematic map, a specific representation of the information content is adopted, which is shared among all the subjects who use the e-Atlas to understand the situational picture.

The layers of the e-Atlas can be organized according to three main functional groups (FG):

- **FG 1 – background**: the layers in this group provide the base information for the further representation of the thematic maps. Generally, the layers of this thematic group do not vary significantly in the period in which the e-Atlas tool is used. However, the content of the layers must be kept updated with the latest available information so that they are as representative as possible of the reality affected in the occasion of an event.
- **FG 2 – informant sources system**: the layers in this group illustrate the characteristics of the informant sources used for the acquisition of the informative data and the characteristics of the buffer areas used for spreading the punctual information. The management of this group requires occasional updates of the layer content during the preparedness phase when changes in the informative sources are implemented.
- **FG 3 – post-event data and elaborations**: the layers in this group are created and updated after each adverse event and show the information concerning the situation, using both the direct representation of informative data and the outcomes of elaboration processes developed according to the pre-codified evaluation algorithms.

These functional groups can be, in turn, subdivided into further subgroups according to the characteristics (number, typology and quality) of the data in the layers.

3.3. Representation of thematic maps and views

The thematic maps are generated through the combination of layers (Fig. 6), which are organized into thematic groups. Each thematic map aims at representing a specific topic that is functional for the description of the situational picture. The thematic maps adopt a specific representation of the content, through symbols and legends defined and used on the basis of the representativeness needs of each map. The representation adopts a common and shared language used by all the users of the e-Atlas.

Through the composition of the various thematic maps and layers, decision-makers using the e-Atlas can compose the views that they deem as useful for understanding the demand that characterizes their organization or institution and that allows outlining the response.

4. Application

The structure of the e-Atlas previously illustrated was implemented in the activities of the Interreg ARMONIA project (“Accelerometric real-time monitoring network of sites and buildings in Italy and Austria”), and this specific application of the e-Atlas was called ARMONIAtlas. The Interreg ARMONIA project, financed by the European Regional Development Fund Interreg V-A Italy-Austria 2014–2020 [18], aims to strengthen the collaboration between the civil protection institutions of Italy and Austria for risk prevention, by developing cross-border strategies in the management of disasters caused by natural hazards, to accelerate and facilitate rescue operations. The project partners are the Na-

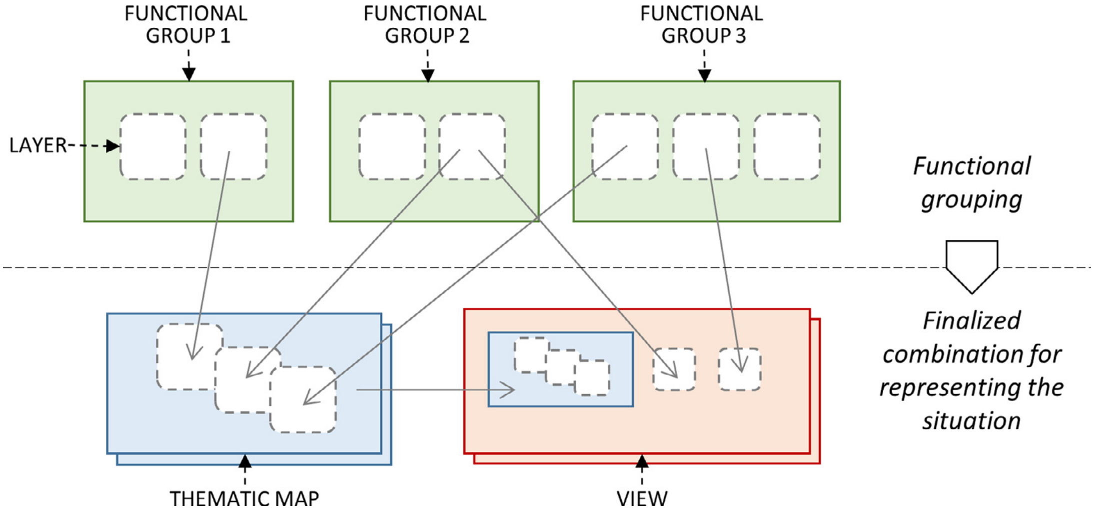


Fig. 6. Schematic representation of how thematic maps and views are defined.

tional Institute of Oceanography and Experimental Geophysics (OGS, I), University of Udine (UniUD, I), University of Trieste (UniTS, I), University of Innsbruck (UniINN, A), Zentralanstalt für Meteorologie und Geodynamik (ZAMG, A), Regional Civil Protection of Friuli Venezia Giulia (RCP-FVG, I) and Regional Civil Protection of Veneto (RCP-V, I). The project concerned the cross-border area between the two involved nations, mainly comprising the Friuli Venezia Giulia and Veneto Italian regions.

The ARMONIAtlas is a digital atlas shared online in which the various ARMONIA partners, after a seismic event, send data from their seismic monitoring networks to generate thematic maps for representing the situational picture in the project area. Seismic events are localized in almost real-time (within one minute after the event) using the information of the seismic networks in the area. The ARMONIAtlas has been installed in the servers of the RCP-FVG and any institution connected to the dedicated web page can see and use the ARMONIAtlas. This creates a data interchange network and allows sharing the situational picture among various institutions also in a trans-border context.

In particular, the ARMONIAtlas is developed for pursuing the following objectives:

a) a transnational sharing of data in a very short time, thus generating a unique and shared framework on which to develop emergency management strategies;
b) a continuous update of the representation of the situation, after each relevant seismic event;
c) possibility to view data referring to past events, for comparison and subsequent analysis.

After establishing the objectives to be met in coordination with the operators of the RCP-FVG and the other partners of the project, the SPRINT-Lab researchers of UniUD identified the main informative sources that were available for implementation of the ARMONIAtlas in the project. Then, on this basis, they defined the main thematic maps useful for decision-makers working in the EMP, and developed algorithms to process informative data (some data are directly processed by the various research groups proving the information, i.e., OGS, UniTS and ZAMG). Moreover, researchers designed the symbols and legends of the thematic maps, to standardize the input data from the monitoring networks and for post-processing. The ARMONIAtlas is a web GIS system based on Lizmap [42] and managed offline using QGis [43]. It was developed by the collaborative work of SPRINT-Lab and RCP-FVG with the other partners, and it allows to acquire the data, represent them in real-time on map support and view the thematic maps and views through a specific ARMONIAtlas web page, in which accredited user can access also from remote.

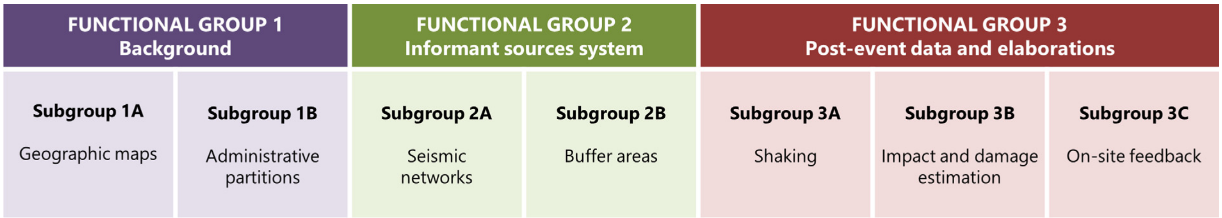
4.1. Architecture

According to the structure illustrated in the previous Section, in the following, we summarize how the three main steps at the base of the e-Atlas architecture have been applied for the creation of the ARMONIAtlas.

Concerning the first step (identification of informant sources and information gathering), the following informative sources have been identified and are currently used in the ARMONIAtlas.

- **Cartographic and administrative data**: the adopted cartographic base map is OpenStreetMap, and the administrative data has been provided by the institutions involved in the project.
- **Census data**: the Italian ISTAT 2011 census data [44] provides knowledge on the territory, and in detail, on the built environment for Italian Regions. In Austria, only municipality and regional borders are implemented.
- **Seismic ground motion sensors**: in the project area there are various seismic networks, both for the measures of ground motion and the seismic shaking in buildings.
    - ○ **Seismic sensors for the measure of the ground motion**: a large number of seismic stations belonging to different monitoring networks are active throughout the project area (Veneto and Friuli regions in Italy, Austria, as well as the neighbouring territories of Trentino Alto-Adige region (I) and Slovenia), and are included in the e-Atlas.
    - ○ **Seismic sensors in buildings**: in the area, there are seismic sensors located inside the sentinel buildings, distributed mainly in Friuli Venezia Giulia and to a lesser extent also in Veneto (and one building with sensors in Austria). The sentinel buildings (which are generally public buildings) were quickly characterized before the installation of sensors, using microtremor measurements to identify the main characteristics of their response [38] and define the most suitable position for the installation of a sensor on the top floor and eventually on the bottom.

The second step adopted for setting up of the ARMONIAtlas was data cataloguing and processing. Data have been catalogued in the three main functional groups previously described. In the ARMONIAtlas, each group has been subdivided into two or more subgroups (Fig. 7), as described in the following. Other subgroups could be simply included if required.



FUNCTIONAL GROUP 1 Background		FUNCTIONAL GROUP 2 Informant sources system		FUNCTIONAL GROUP 3 Post-event data and elaborations		
Subgroup 1A Geographic maps	**Subgroup 1B** Administrative partitions	**Subgroup 2A** Seismic networks	**Subgroup 2B** Buffer areas	**Subgroup 3A** Shaking	**Subgroup 3B** Impact and damage estimation	**Subgroup 3C** On-site feedback

Fig. 7. Subdivision of functional groups in subgroups in the ARMONIAtlas.

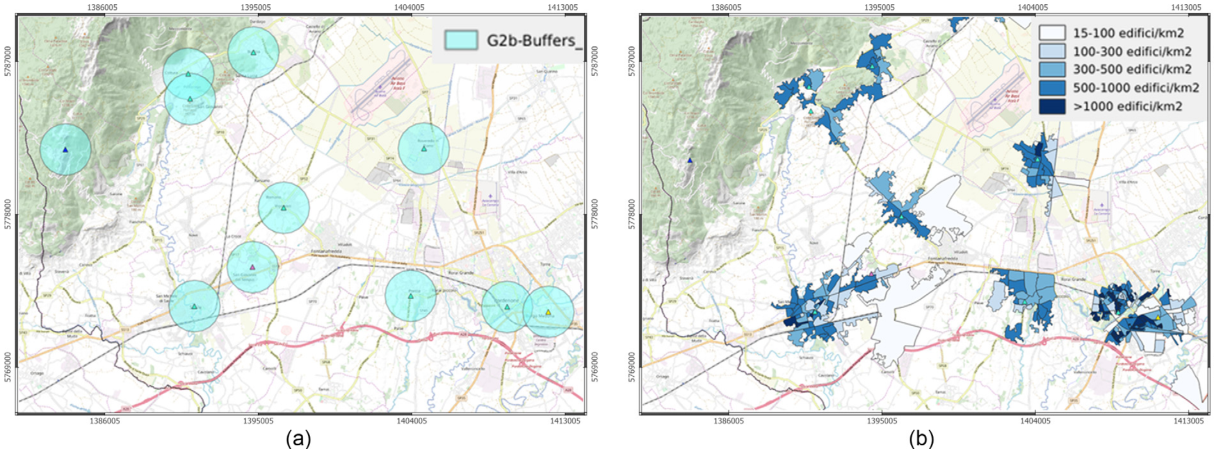


Fig. 8. Examples of buffer areas around seismic sensors. The areas are defined using either (a) using a pre-defined distance from the seismic sensor, or (b) considering the density of buildings in the zones surrounding the seismic sensor.

- **FG 1 – background:** this thematic group is composed of layers that can generally be used as a basis for most views, and above which the other information layers are represented. FG 1 is divided into two subgroups.
    - ○ **Geographic maps** (1A), includes maps for outlining the characteristics of the territory. In this group, there are geographical maps of the areas, maps with the location and characterization of the faults [45], and the map with seismogenic boxes [46]. Moreover, in Friuli Venezia Giulia, the map of the geomorphological scenarios is represented [47].
    - ○ **Administrative partitions** (1B), includes political maps, census data and other related information.
- **FG 2 – informant sources system**: FG 2 groups the layers with information concerning the characterization of the informative sources which mainly concerns seismic monitoring stations and surrounding buildings. This thematic group is divided into two subgroups.
    - ○ **Seismic networks** (2A), contains layers referring to the seismic networks in the area, with characteristics of the instruments, and the area where they are installed (such as, the classification of the site at the station). In this group, there are also layers with information concerning the rapid characterization of the sentinel buildings [38], with the main geometric and structural characteristics of each sentinel building, as well as the characterization of the site where each sentinel building is located.
    - ○ **Buffer areas** (2B), represents the areas surrounding the seismic stations, on which damage estimation assessments are carried out after an event. The buffer areas are defined by considering either the area within a specific distance from each sensor (Fig. 8(a)) or the density of buildings in the areas surrounding the sensors (Fig. 8(b)). In the buffer areas, building vulnerability assessments (e.g., using census data [48]) allow, after an earthquake, to estimate the potential consequences in terms of damage using, as hazard information, the ground motion parameters derived from measures of the station into the buffer area.
- **FG 3 – post-event data and elaborations**: FG 3 groups the layers that represent the information coming from the area affected by the event and which are updated after the occurrence of every earthquake (with above-threshold magnitude). This thematic group is divided into three subgroups:
    - ○ **Shaking** (3A) includes all the layers referring to the ground motion parameters, representing them both with punctual information, using the parameters to the seismic stations, and in a spatial way, through Shakemaps developed by the OGS and UniTS partners of the project. The punctual values of the ground motion parameters are the basis for further elaborations concerning the damage estimation.
    - ○ **Impact and damage estimation** (3B) subgroup comprises the data referring to the impact of the event and the layers of damage estimation obtained starting from ground motion parameters. The damage assessments have been developed using the methodologies described in [49,50,51]. For masonry buildings, empirical relations are used to assess the cumulative damage in case of aftershocks or new mainshocks [52]. The content of these layers is in turn used to obtain an estimate of the structural damage that occurred in the buffer areas.
    - ○ **On-site feedback** (3C) subgroup is prepared for organizing the layers containing information on feedback from RCP volunteers. This subgroup is currently empty, but it is planned to include in this group-specific layers acquired through procedures defined in another project in the Friuli Venezia Giulia region [39].

Finally, the third step implemented for setting up the ARMONIAtlas was the preparation for the representation of thematic maps and views in the case of an event. The thematic maps have been defined using the previously described layers, and eventually combining them according to functional purposes. As for the layers, the thematic maps of the ARMONIAtlas are generated suddenly after an above-threshold earthquake.

When further events occur, the entire procedure is repeated for the creation of new maps, to ensure that the representation of the situational picture is as consistent as possible with the emergency evolution. Some examples of thematic maps are illustrated in the following.

Decision-makers can use the above-described thematic maps, as well as single layers of the ARMONIAtlas to define the views for the EMP, viewing, for example, more thematic maps contemporary to better outline the situation according to their needs.

4.2. Operation scheme

Fig. 9 summarizes how ARMONIAtlas works. After an earthquake, the view generation process is activated by receiving monitoring data from the area affected by the adverse event, and the level of information of monitoring data could change depending the available information for each specific area. In the ARMONIA project, Level I corresponds to the network of seismic sensors for the measurement of ground motion, Level II to the network of seismic sensors in buildings, and Level III to the on-site people feedback. The monitoring data are processed by the various subjects that deal with the acquisition of the records and their processing. The processed data are sent to a dedicated server located at the headquarters of the RCP-FVG, making all the recordings of the different networks converge. Specific algorithms are implemented in the server for data cataloguing as well as for processing to obtain additional layers necessary for the definition of the thematic maps. Since various areas have different levels of information, the thematic maps available for each area could vary. The thematic maps are made available on the ARMONIAtlas web page, and they can be combined to customize specific views for the various users of the ARMONIAtlas. A view is therefore a set of thematic maps that decision-makers of each organization decide to activate and view to examine and delineate the emergency situation, for understanding the demand and outlining the response. The above configuration is simply replicable in other servers aimed at managing emergencies.

Given the open architecture of the ARMONIAtlas (that follows the structure of the e-Atlas), it is simple and quick to add new thematic maps or modify the existing ones, according to specific needs that could arise after an event, as well as to include new areas.

It's worth noting that in the ARMONIAtlas the level of information changes depending on the area, as illustrated in Table 1. In the ARMONIA project, in the Friuli Venezia Giulia region, all three levels have been implemented, while in Veneto Level II provides only a partial coverage of the territory, and in the other regions (Trentino alto Adige in Italy, and Carinthia and Tyrol in Austria) there is only Level I information.

4.3. Tests during exercises and small earthquakes

The ARMONIAtlas was tested during exercises developed in the ARMONIA project and in the occasion of small earthquakes registered in the project area. During the ARMONIA exercises, all the processes for the creation of thematic maps and views have been tested, and this allowed to improve the procedures for the transmission, elaboration and sharing of information, standardizing and adapting them to the needs of generating the views. In the following, we show some examples of thematic maps created during the exercises of the ARMONIA project.

- **Ground motion parameters and shakemaps**: this thematic map aims at providing a quick assessment of the impact and extent of the seismic event, allowing decision-makers to point out and understand where focusing the attention. The thematic map includes the main ground motion parameters measured at the seismic stations, together with the main characteristics of the seismic sensors and of the site (or building) where stations are installed. Moreover, the map shows the base layers with the geographic and administrative information, and, In Friuli Venezia Giulia, the geomorphotypes. Fig. 10 shows a map created after a real earthquake with M_w 4.3 occurred in Slovenia on 17th of July 2020.
- **Warning levels at municipality level**: this thematic map aims at summarizing the warning levels esteemed for each municipality, and this allows the activation of specific emergency procedures that have been pre-codified. This map is defined for Friuli Venezia Giulia and Veneto Regions, which have pre-defined emergency procedures. For

Table 1
Coverage of the three levels of information in the areas mapped by the ARMONIAtlas.

			II	III
	Italy - Friuli Venezia Giulia	yes	yes	yes
	Italy - Veneto	yes	partial	no
	Italy - Trentino Alto Adige	yes	no	no
	Austria - Carinthia	yes	no	no
	Austria - Tyrol	yes	no	no

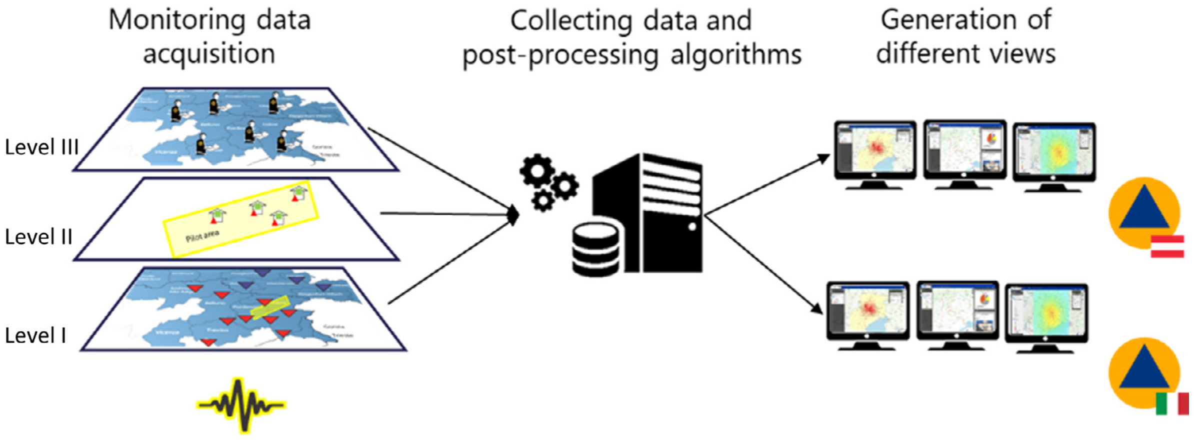
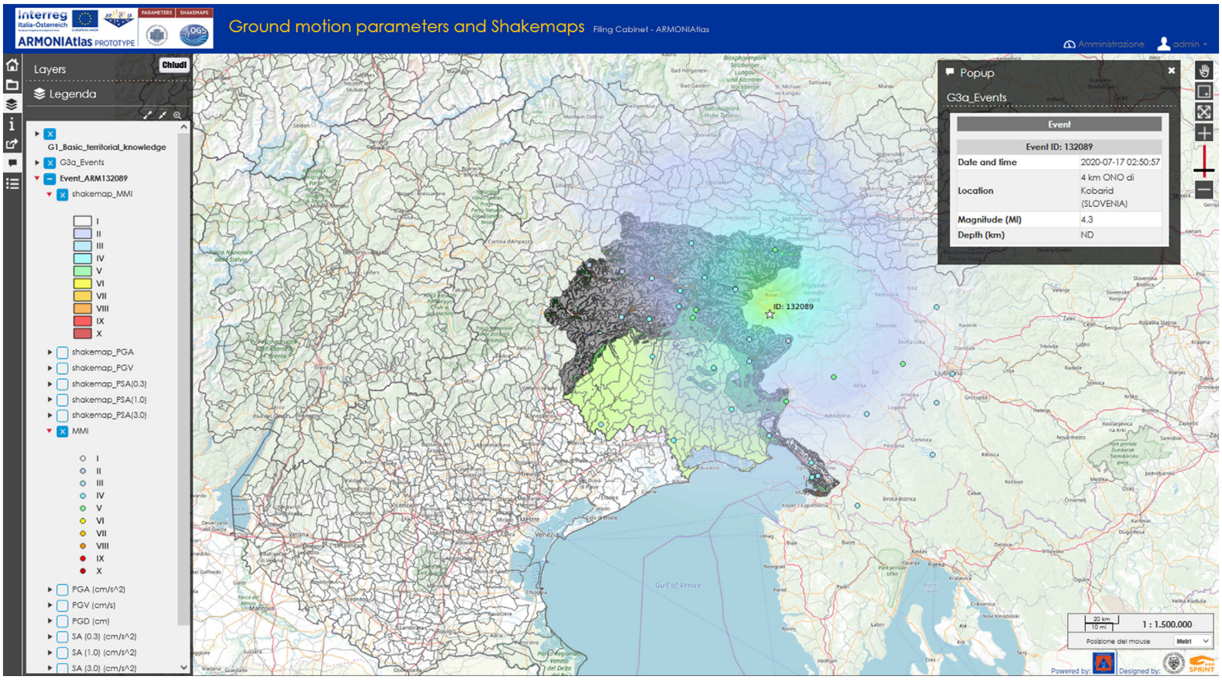


Fig. 9. Operation scheme of the ARMONIAtlas.



Popup

G3a_Events

Event	
Event ID: 132089	
Date and time	2020-07-17 02:50:57
Location	4 km ONO di Kobarid (SLOVENIA)
Magnitude (Ml)	4.3
Depth (km)	ND

Fig. 10. Thematic map showing the ground motion parameters and shakemaps. The figure shows the punctual values of macroseismic intensity (MMI, dots in the map) and the MMI shakemap, calculated after a real event with Mw 4.3, occurred on 17th of July 2020 in Slovenia (white star in the map). In Friuli Venezia Giulia, the map shows the geomorphotypes, in the other regions the base map with geographic and administrative information. The left side shows the legend, and the popup in the right side summarises the main characteristics of the event that originated the thematic map.

a detailed description of these procedures, see [39,53]. Fig. 11 shows an example of a thematic map on this issue, prepared for an exercise developed during the ARMONIA project. In the map, the colours of the municipalities refer to the “A, B, C” codes of the three warning levels, and the white municipality areas are those without warnings ("N" class).

- **Correlation between ground motion parameters and macroseismic intensity**: the purpose of this thematic map is to show a first evaluation of the potential consequences of the earthquake. The

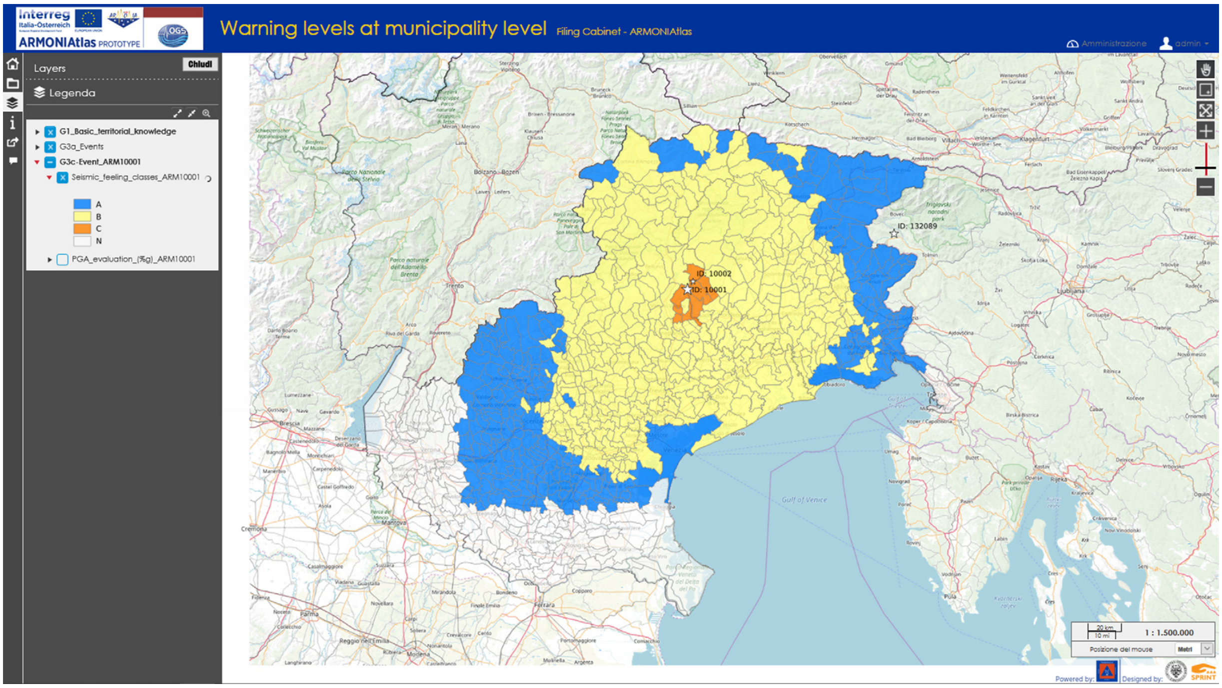


Fig. 11. Thematic map highlighting the warning levels at municipality level of a simulated earthquake (M_W=6.1, in the map illustrated by the white star with ID=10,001). The coloured areas reflect the administrative boundaries of municipalities; the colours refer to the warning levels esteemed for each municipality (from worst case to better: C, B, A, and N).

map shows the macroseismic intensity ranges calculated in correspondence to the ground motion measurement points, differentiating the evaluations for masonry and reinforced concrete buildings. The outcomes are calculated using the correlation between ground motion parameters and EMS-98 macroseismic intensity values [54,55]. The symbol in correspondence of each buffer area summarises the maximum and minimum values of the macroseismic intensity esteemed using the various methodologies. Fig. 12 shows an example calculated during an exercise, considering a M_W=6.1 earthquake.

- **Damage estimation for sentinel buildings and buffer areas**: this thematic map provides an estimate of the potential damage in correspondence of sentinel buildings and the surrounding buffer areas. In this map, the damage estimates are evaluated by applying the macroseismic [50] and Probit [49] methods. Fig. 13 shows an example calculated during an exercise with M_W=6.1 earthquake.

One of the needs that emerged during the tests was the management of multi-event situations, considering successive earthquakes affecting the same area. This case was tested during an exercise, when the occurrence of two subsequent events was tested: the first with M_W=5.0 and the second, in the same area of the first, with magnitude M_W=4.2. After each earthquake, the vulnerability of masonry buildings is modified considering the damage estimated for the event, thus allowing to consider the progression of damage in case a new event occurs. Fig. 14 shows the thematic maps automatically created during the exercise starting from the simulated ground motions of the exercises. It is possible to observe that the second, minor, earthquake caused the increase of the damage situation in one buffer area evaluated by the methodology.

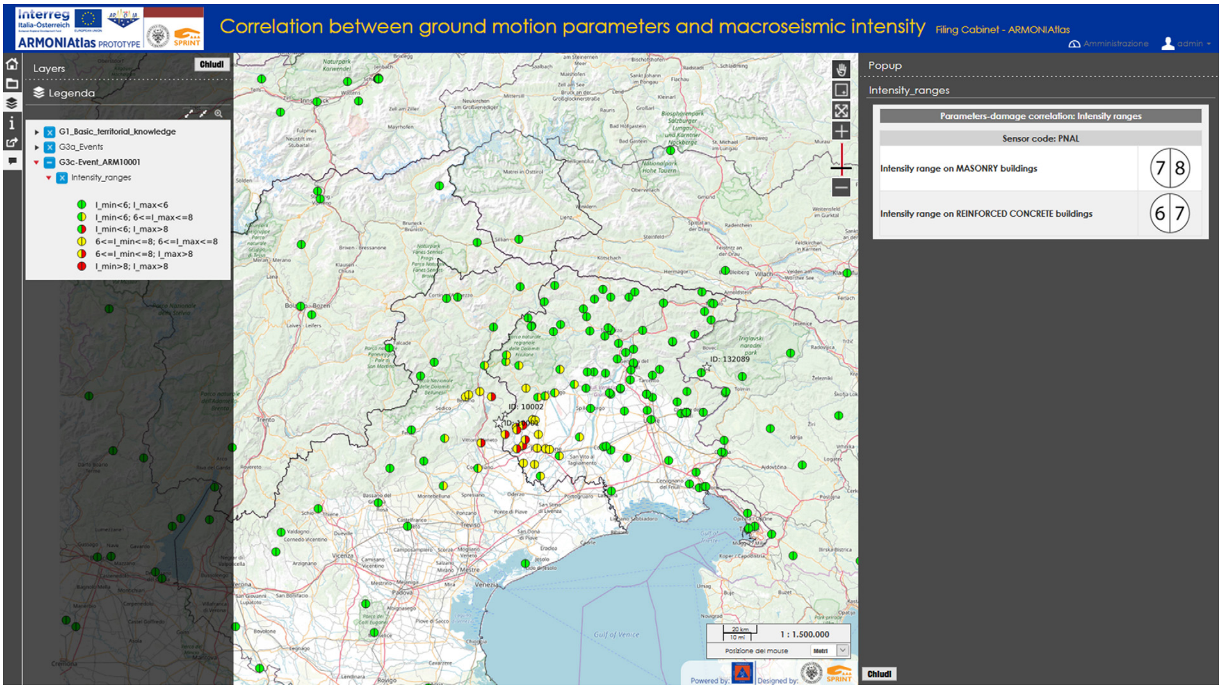
Thanks also to the occurrence of real events, albeit minor ones. It was possible to improve the management procedures, responding to the needs of different users. During these events, the importance of inter-institutional collaboration emerged, which has to established during the preparedness phase. This can lead to effective contributions in preparing for the management of situations resulting from stronger shocks.

Moreover, tests (both exercises and real events) highlight the need to integrate into the ARMONIAtlas all the maps that allow understanding the post-event demand, thus including also the maps concerning the on-site people feedback. In the Italian area of the ARMONIA project, regional civil protection (RCP) volunteers are trained to collect specific information on the seismic resentment in a structured and pre-codified way [39,56]. RCP volunteers are considered as observers “in the field”, who, following a seismic event, acquire information in the affected areas and then transfer it to the EMP databases according to pre-coded procedures. Currently, maps derived from on-site people feedback are implemented in a separated web gis, but the tests show the usefulness of a shared, collective and harmonized representation of the information from the territory. Accomplishing these requests, the on-site people feedback will be included soon in the ARMONIAtlas. At an operational level, civil protection operators describe the ARMONIAtlas tool as extremely important for decision-makers in EMP to have an immediate assessment of the extent of the shaking and damage distribution, allowing the identification and implementation of suitable countermeasures in a quick and targeted manner.

In the case a strong earthquake will occur, it is very probable that no information would be available in real time for the epicentral area, where communication network would probably be down. However, the data will arrive from surrounding areas, thus allowing to circumscribe the most affected area (which would be assesses in detail later on).

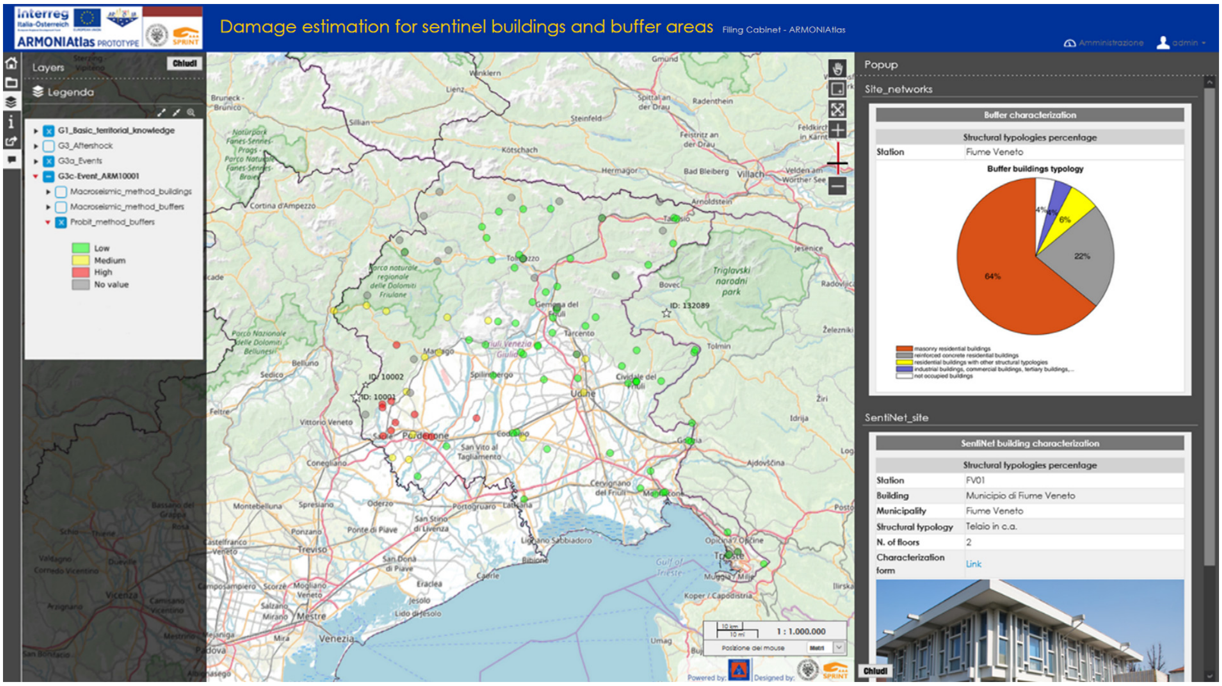
5. Conclusion

The management of a disaster entails outlining the post-event situation, understanding the demand and identifying suitable action plans for the response. Then, it requires a harmonized and coordinated response, that takes into account the involvement of multiple actors, with potentially different procedures, especially in the case of cross-border events. The above observations led the Authors to establish the basis



Parameters-damage correlation: Intensity ranges	
Sensor code: PNAL	
Intensity range on MASONRY buildings	7 8
Intensity range on REINFORCED CONCRETE buildings	6 7

Fig. 12. Thematic map showing the esteemed macroseismic intensity values (MMI) in correspondence of the buffer areas. The white star with ID=10,001 shows the position of the epicentre. The two coloured semicircles that compose the symbols in the map refer to the maximum and minimum MMI esteemed values. The legend in the left side summarises the meaning of the symbols. A pop-up for each buffer area shows the MMI values calculated for masonry and reinforced concrete buildings.



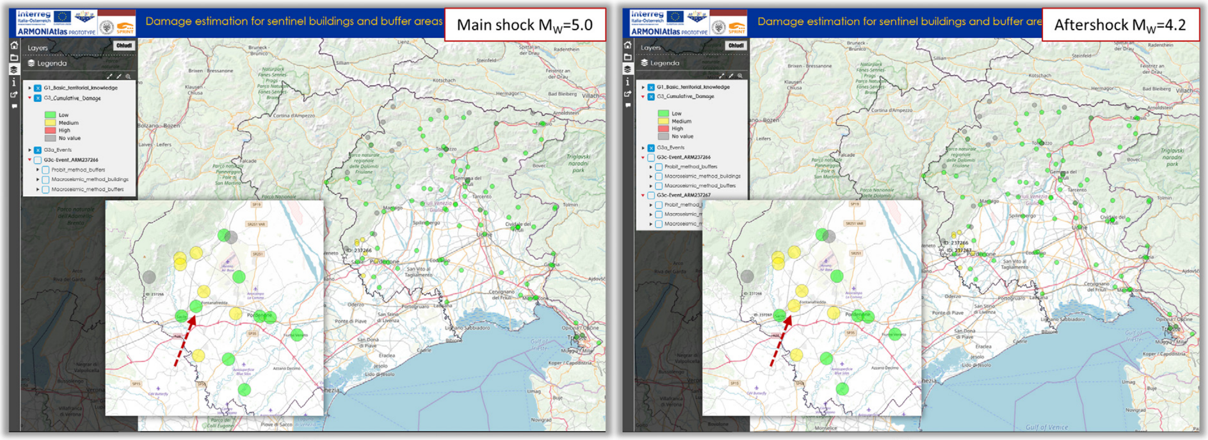
Buffer characterization

Structural typologies percentage	
Station	Fiume Veneto

SentiNet building characterization

Structural typologies percentage	
Station	FV01
Building	Municipio di Fiume Veneto
Municipality	Fiume Veneto
Structural typology	Telaio in c.a.
N. of floors	2
Characterization form	Link

Fig. 13. Thematic map showing the damage estimation for sentinel buildings and buffer areas. The figure shows the outcomes calculated through the macroseismic method. The pop-up in the right side shows the distribution of buildings in the buffer area according to their building and structural typology.



(a) (b)

Fig. 14. Thematic maps showing the damage estimation for buffer areas calculated using macroseismic method after the main shock (a) and the aftershock (b). The dashed red arrows in the two figures point an area in which the damage evaluation increases after the second shock.

of an e-Atlas, aimed at providing decision-makers with the elements of information substantial for outlining the post-event situation and understanding the related demand for emergency decision-making. In detail, the e-Atlas illustrated in this paper is focused on the post-earthquake situation. The application of the e-Atlas to a real case during the Interreg Italia-Austria ARMONIA project proved that the conceptual framework at the base of the e-Atlas is suitable for the development of web GIS maps for supporting decision-making processes in the response phase, with the following strengths and weaknesses.

- The tool allows for a progressive reconstruction of the situational picture, also accounting for potential sudden changes of the current situation, caused, for example, by the occurrence of other adverse events (e.g., aftershocks).
- The e-Atlas has to be implemented during the preparedness phase, and it requires training and knowledge on how to use it. These should be provided both by specific preparation and by continuous use, especially through periodic drills. Albeit this can be considered a weakness, it could also be considered as a strength since it requires decision-makers to be up-to-date and supports the improvement of problem-solving skills.
- The implementation and use of the e-Atlas require decision-makers to examine and review the information useful for representing the post-event situation in a pragmatic, finalized and substantial way. For this purpose, decision-makers can decide to add some information to the e-Atlas in order to create specific views, but also (and this should be preferable) to remove or reduce the represented information. Therefore, the e-Atlas becomes also a tool for training decision-makers on pragmatism, which is an essential skill for decision-making in an emergency.
- The e-Atlas makes allowance for the potential sudden change of the post-event situation, due to the occurrence of another adverse events. In this case, it would be required to reconstruct the post-

event situation all over again. This aspect highlights that, in a context that could quickly evolve, dynamic focuses on substantial issues should be preferred over an in-depth analysis of the entire situation, that could require a too long time for the evaluation, and that could be no more representative of the current situation.

- The e-Atlas has been developed for the seismic case, but it can be simply adapted to be implemented for the management of other hazards (such as flood, strong wind, and fire hazards).

The e-Atlas has been used for setting up the ARMONIAtlas. That specific e-Atlas was tested during exercises and small events occurred in the project area. It will remain active for providing information to decision-makers when large earthquakes will occur, when it would also be possible to experiment the functionality and usefulness of the e-Atlas for decision-making purposes in non-simulated conditions. Further tests will allow to verify the efficacy and functionality of the e-Atlas, providing also useful feedback for its potential enhancement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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