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Master of Science in Civil Engineering for Risk Mitigation

DESIGN OF A WEBGIS PLATFORM TO SUPPORT DAM CRISIS MANAGEMENT IN SEISMIC EMERGENCY

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Table of contents

List of figures

List of tables

Abstract

When an earthquake hit an area, emergency management procedures are crucial in order to mitigate effects on the territory and, most of all, to reduce losses among involved population. The complexity of this process may increase if the site is characterized by the presence of critical infrastructures, such as a dam system. It is clear that efficiency in interventions can be achieved only with planned actions based on an accurate knowledge of the territory.

For this reason, the current study aims to design a tool for improving the emergency management, in particular with the development of a platform devoted to geospatial analyses and consultations of document, containing useful information to be considered in a dam crisis management. Aiming to provide a practical example, the whole system was populated with information coming from a study-case, Ponte Cola dam (BS, Lombardia Region, Italy).

A prototype of the designed platform was built in GeoNode environment. Aiming to obtain a suitable result in terms of usability, the system was organized in levels, so that different datasets could be accessed from different user categories, such as Civil Protection operators and citizens, who could e.g. retrieve on the platform best practices for self-rescue. On the side of geospatial functionalities, the operators would be allowed to visualize on a map a selection of layers that could help in assessing the territory conditions and establishing priorities for intervention, depending on available data.

Other aspects of emergency workflow were also considered with the aim of providing new tools for its improvement, such as an online form specially built for dam inspections.

The proposed project provides some useful instruments that could affect positively crisis management procedures. Furthermore, its customizability would allow the specification of the platform for many different calamitous events. Several expansions would be possible, in order to increase the potential of the system, e.g. its combination with support applications addressing the aspect of field-reporting, leading in perspective to a robust integration into emergency management workflow.

Sintesi

Quando un’area viene colpita da un terremoto, le procedure di gestione dell’emergenza sono fondamentali per la mitigazione degli effetti sul territorio, soprattutto per ridurre le perdite tra la popolazione colpita. La complessità di questo processo può aumentare se il sito è caratterizzato dalla presenza di infrastrutture critiche quali una diga.

È chiaro che l’efficienza nella fase di intervento può essere raggiunta solo con azioni pianificate che si basino su una conoscenza dettagliata del territorio. Per questa ragione il presente studio si pone l’obbiettivo di elaborare uno strumento di supporto alla gestione dell’emergenza, sviluppando una piattaforma finalizzata ad analisi geospaziali e alla consultazione di documenti utili.

Un prototipo della piattaforma è stato sviluppato in ambiente GeoNode, e caratterizzato cono dati relativi al caso studio della diga di Ponte Cola (BS, Lombardia). Per incrementarne la fruibilità, il sistema è stato organizzato su più livelli, in modo che diversi set di dati fossero accessibili da specifiche categorie di utenti, tra cui Protezione Civile e cittadini. Sul fronte delle analisi geospaziali gli operatori potranno visualizzare su una mappa una selezione di layer che li aiuti a verificare le condizioni del territorio e di conseguenza a stabilire le priorità di intervento.

Nello studio, altri aspetti del processo di gestione dell’emergenza sono stati affrontati, cercando di offrire nuovi strumenti per supportare le operazioni, tra cui un modulo interattivo realizzato appositamente per supportare le ispezioni dei corpi diga.

Il progetto fornisce alcuni strumenti utili che potrebbero contribuire positivamente alla gestione dell’emergenza. Inoltre, la personalizzazione apre alla possibilità di costruire piattaforme direttamente rivolte alla gestione di varie tipologie di eventi calamitosi. Ulteriori espansioni volte a incrementare il potenziale del sistema sarebbero poi possibili, tra cui la combinazione della piattaforma con un’applicazione di segnalazione di criticità dal territorio. In prospettiva, questo sistema costituirebbe una robusta integrazione alle procedure di gestione dell’emergenza.

1. Introduction

Safety is a dynamic non-event.

The reported statement, actually paraphrased from an article in *California Management Review* by professor Karl Weick (Weick, 1987), can be considered as a key concept of disaster management. It can be understood addressing population safety (intended as the absence of events, and therefore consequences) as the final goal of management procedures, that is reachable only through performing specific operations in order to analyze, prevent and respond to possible calamitous events. Civil protection role is mainly embedded in this kind of workflow, and it is actually deployed with taking advantage of several instruments and cooperating with different stakeholders.

This thesis is exactly devoted to present the design of a tool to support Civil Protection in crisis management, in the form of a WebGIS platform, meant to improve operations efficiency in case of intervention during seismic emergency in an area characterized by the presence of one or more dams.

The current text is actually the evolution of the experimental project *Service to support earthquake dam safety inspection and securing downstream settlements* (Conversi et al., 2021) developed by the author's team within the context of *Geospatial data processing to support seismic emergency management* academic module.

In particular, the project aimed to the identification of innovative tools for risk mitigation, among which an operational WebGIS, designed according to a predefined logic and implement, to support the various phases and the different activities of post-earthquake crisis management and early recovery. Among the several proposed territorial assets to be addressed, the group choice fell on the analysis of a real dam system, proposed for the first time in the current academic year. The project was written with reference to the seismic swarm that affected Central Italy between the end of 2016 and the early 2017, with a specific focus on Campotosto lake dam system, that in the considered occasion required the activation of inspection procedures.

As mentioned, the current work was built starting from the same application context, aiming to furtherly develop and implement the WebGIS platform and, most of all, to integrate it in a suitable way within Italian Civil Protection intervention framework.

The main goal of the project platform is the provision of a tool specifically built for improving procedures, information sharing and geodata elaboration, to be employed in Civil Protection control centers. Here, operators and authorities representatives (as decision makers) would take advantage of the platform, in order to organize information in an effective way and, as a consequence, take decisions on field intervention, such as resources distribution or priorities establishment.

The organization of the thesis includes two different sections, the first one (until chapter 3) is devoted to an overview of the work and employed technologies, while in the second (from chapter 4) the complete discussion of project implementation and its integration in the study-case will be presented.

More in detail, the first aspect to be discussed will be a project summary, containing pieces of information on dams behavior in seismic events and corresponding regulations and previsions on how the project will be framed within existing procedures; this general paragraph will be followed by a flowchart of the steps performed to develop the whole work.

Subsequently, a detailed discussion of WebGIS architecture and its components will be carried out, with specific regard to the set of software needed to build a platform, correlated with descriptions of the specific role in the workflow and real applications.

The second part of the work will be opened by the description of the study-case of Ponte Cola dam, chosen as an example for illustrating the potential of the project platform; the chapters devoted to this aspect will be structured on the base of official documents that regard emergency management in the area, complemented with additional pieces of information on Italian Civil Protection organization and operational issues.

Then, the actual prototype of the WebGIS platform will be presented, showing the software interfaces and analyzing extensively the possibility of employment made available for the different users, along with a discussion on strong points of the system and possible further developments. Among the implemented WebGIS contents, also a Fast form for damage reconnaissance to be used by operators for dams inspections will be included.

Lastly, a proposal for a future expansion of the system will be presented, with particular regard to the design of a secondary platform accessible through mobile devices and devoted to management of information flow in upload.

2. Project setting

2.1 Problem framing

The main framework of reference for the current thesis is the one of Civil Protection interventions within the context of management of an ongoing seismic emergency.

In general, it is possible to state that Italian Civil Protection Department is a substructure of Italian Council Presidency and covers the role of official provider of guidelines and activities for risk prevention, jointly with the coordination of National Civil Protection Service. It is furthermore responsible of the operators on the territory, both from the training point of view and from the intervention one (Dipartimento della Protezione Civile, 2021). Indeed, the main goal of the whole Civil Protection structure is the provision of effective assistance to the population involved in a major emergency.

With specific reference to the field of interest of the current project, which is the Civil Protection intervention procedure in case of an earthquake hitting a dam-populated area, it should be underlined its multi-risk nature, particularly characterized by the presence of dams. These are indeed critical infrastructures that requires to be carefully monitored in case of a seismic event, due to their proneness to be damaged and, most of all, to the fact that the dams themselves can represent a serious hazard for the whole downstream area. It would be no-sense to treat an area characterized by the presence of one or more dams as a normal one, if an earthquake occurs and it could instead lead to the underestimation of possible outcomes and, as a consequence, expose population to higher risk.

Specific regulations are then required to be respected for operating in this context, that are characterized by the integration of several different expertise coping for mitigating the possible outcomes and providing efficient responses in crisis time. These guidelines (enacted by local authorities and Civil Protection) embed a set of structured intervention schemes in which the diverse stakeholders are coordinated with the aim of covering all the different aspects of a dam-crisis. As an example it is possible to mention the necessity of inspections of the dam body that will be immediately activated in consequence of an earthquake and that have to be structured in a certain manner (detailed in paragraph 8.5), in order to allow the decision maker to understand which is the situation on field and act coherently, with the goal of facing in the best way possible secondary events.

In this context, it appears clear that a structured monitoring system is necessary to be able to observe the evolution of response to the earthquake, prevent failures or, if not possible, to mitigate their impact. From this statement rises the base concept of the application of the current thesis project, aimed to provide Civil Protection a powerful and customizable tool to support emergency management.

In particular, the tool will be structured as a WebGIS platform in which data on the territory will be archived and geospatial analyses performed, in order to obtain an integrate and detailed overview of the territory conditions during an emergency. On this base, the decision maker would be able to visualize the needed information in an efficient way, querying the layers depending on its needs, with the result of decreasing the time of response. Furthermore, also the procedure of dam body inspections would be improved, through the employment of a digital form to be filled in-situ with all the information to be reported, which will be instantaneously be accessible by the responsible authorities.

The proposed platform implementation combines the two aspects of information and data management during an emergency, aiming to increase the whole procedure efficiency; the goal is to reach an integration into real Civil Protection operations and so some considerations on the state of the art could be useful in order to consent to the reader a deeper understanding on the project potential. For this reason, in next paragraph a flowchart is presented, with the aim of addressing the different steps performed during the development of the thesis.

2.2 Methodological workflow

Following the flow outlined in Figure 1, the current paragraph will be devoted to the detailing of performed operations during the different phases of thesis development.

Figure 1: Flowchart of the thesis project.

2.2.1 Flowchart: State of the art

As far as the state of the art is regarded (Figure 1, first step), it is possible to mention that Civil Protection interventions are deployed following the directives of official documents (that will be addressed in detail starting from chapter 4), describing on the different governance level, from national to local, which are the procedures to be enacted and most of all defining a clear and strict cooperation scheme that includes all the stakeholders involved in emergency management of the territory. The two main plans that are used as a base in this framework are the *Piano Emergenza Diga*, literally, Dam Emergency Plan, and the *Documento di Protezione Civile*, Civil Protection Document, which embeds all the pieces of information related to the area in analysis and, most of all, the intervention schemes.

Referring to the disaster management cycle shown in Figure 2, the two considered aspects of planning and interventions correspond to the orange and red phases, respectively Preparedness and Response one.

Figure 2: Disaster management cycle (ITSA, 2021).

It is clear that in order to have a successful application in field of this workflow and obtain a mitigation of the event possible impact over the territory, reducing losses among people, all the different aspects of the cycle must be carefully addressed and connected each other. It is exactly in the concept of communication between emergency management phases that the core of the current project lies.

Indeed, the achievement of positive outcomes in the context of reference can be reached only if Preparedness (and so plans) and Response (interventions) are efficiently connected. This was the main consideration kept in mind while analyzing the previously mentioned plans and the corresponding intervention procedures, trying to understand whether the tools available to the present day were sufficient or not to guarantee the effective interconnection among planning and response and, as a consequence, if the project platform could fulfill the actual needs.

As an outcome of this preliminary overview, it is relevant to highlight that even though the reference plans are quite recent, they do not actually provide nor suggest particular tools or platforms for supporting emergency management procedures; their contents are focused on prescriptions and analyses that may take into account modern software, but actually the outcomes are still presented in a traditional way. One of the multiple examples that can be retrieved is the one of hydraulic simulations, which were obviously performed with specific programs and displayed in a GIS environment, but whose results are nevertheless presented in traditional cartographic tables, attached to the PED.

It is therefore clear that addressing the planning aspect no WebGIS applications seems to be integrated, but it is relevant to state that, on the response side, something different can be achieved.

Indeed, Italian Civil Protection is on its way for the informatization (or better, digitization) of its instruments, following the evolution of the society and taking advantage of new technologies. This statement can be strengthened by addressing SEIS-MEC WebGIS platform (Goretti, 2021), recently developed by Italian Civil Protection in partnership with Eucentre foundation. This project is devoted to support National authorities of Mediterranean countries into facing seismic emergency, through a WebGIS in which real-time scenario based on opensource data can be visualized and accessed. This tool will allow countries to find information of the possible outcomes of a seism impacting their territory, with several levels of detail, and use them as a base for performing simulations, planning or support local Civil Protection bodies. This last goal was addressed by considering two different aspects, the first one is that not all Civil Protection operators are expert GIS users and so the platform was built with a user-friendly interface that does not require particular knowledge on this field; the second aspect is related to the kind of data made available and directly interesting Civil Protection needs, such as available resources spread within the territory and location of means at disposal, in terms of intervention teams, vehicles and shelter-suitable areas.

Coming back to the current thesis, this analysis of Italian Civil Protection interest in adopting modern technologies for supporting field operation confirmed the actual need and employability of the project platform. Furthermore, the development of the SEIS-MEC WebGIS was taken into account for building the platform in a way as suitable as possible with respect to the actual Civil Protection needs, especially referring to the ease required in accessibility of the system and to the resource layer, actually uploaded in the project implementation.

2.2.2 Flowchart: Earthquake impact on a dam system

Moving to the next step presented in Figure 1 flowchart, an analysis of the possible evolution of the crisis, once a dam is hit by an earthquake was performed. First of all, a research on historical events and scientific correlation between dams and seisms was carried out, also taking advantage of the results of a previous assessment, performed for the experimental study on which the current thesis is based (Conversi et al., 2021), focused on Campotosto dams system.

In particular, different aspects were considered, as possible primary outcomes such as direct damages suffered by the dam body or activation of instabilities (landslides) in the area and secondary ones, among which water spill from the reservoir or further damages coming by the interaction of landslides and the dam itself. All of these analyses were used in order to frame the possible evolutions and extent of the events chain, so that suitable data for the intervention on the potentially involved areas could be uploaded in the WebGIS. In this regard, a diagram of the whole set of cascading event that were considered to be (even if remotely) plausible to happen was built and inserted in the platform; this scheme (that can be retrieved in paragraph 8.3) embeds several possibilities, from the less severe ones, like small flooding of downstream areas, to the worst scenario of "Vajont effect", named after the 1963 disaster, that could be driven by a massive rock avalanche occurring into the lake, generating as a consequence a disruptive shockwave that, jointly with water release, would result into the complete disruption of the whole territory downstream.

In addition to these aspects, also the official plans were taken into account in order to better tailor the platform with respect to Civil Protection needs. In particular, the two presented scenarios of water release and collapse were analyzed, and after some discussion, the second one was selected as more meaningful to be represented. As a consequence, the operational workflow for the emergency management and the involved stakeholders were addressed, as described in chapter 7.

2.2.3 Flowchart: Designed WebGIS platform

The three final steps of the flowchart shown in Figure 1 are related to the actual WebGIS platform development. In this case, a preliminary study on architectures and available software was carried out, in order to select an environment that could as much as possible satisfy the author's needs in terms of implementation procedure and results achievement.

This thesis project prototype was developed in GeoNode (GeoServer, 2021) environment and the platform was structured so that different users (united by the common interest of crisis management) could take advantage from it in their own way, as deeply described in chapter 8.

In particular, aiming to provide an application example of the developed system, the platform was populated with data coming from *Geoportale Lombardia* (Regione Lombardia, 2021), with reference to the study-case of Ponte Cola dam, situated in Brescia province, in correspondence of Valvestino lake. Clearly, in order to obtain a more integrated workflow and information set also the official documents and guidelines mentioned in paragraph 2.2.1 were the ones related to the same area and to the dam of interest.

Once the prototype was developed, some weaknesses of the system were carefully considered, aiming to provide solutions to some issues and suggestions on the aspect to be taken into account in case of an actual implementation and publication of the system. In this context a particular idea emerged among the others, related to the possible combination of the platform with a secondary application that could consent data collection and critical situation reporting directly from the field, through mobile devices; although this integration was not implemented in the current project, it will be discussed from a theoretical point of view in the last chapter of the thesis.

3. WebGIS environment

3.1 Geodata sharing

The starting point of the current analysis corresponds to the description of the processes behind the sharing of a WebGIS platform on the net. Indeed, its publication will not be as straight forward as the one of a generic website can be. In the following paragraphs, a general version of a WebGIS platform architecture will be presented, treating which different technologies and software should be present and which is their specific contribution to the system functionalities.

Before going on, a short introduction to Geospatial data sharing on the web and focus on the kind of service that the project is intended to provide might be useful. The dissemination of geospatial data through the internet relies indeed on a common and standardized environment, under the directives of a consortium, called OGC (Open Geospatial Consortium). It is the leading body devoted to the growth of open standards and interoperability of geographic information (Granell et al., 2010). OGC is composed of several private and public entities (from companies to universities) and its principal goal is to define standards for geo-services, so that data and projects can be easily shared and interoperability can be granted. The OGC offers specific guidelines for different services, depending on their main purpose: Web Map Service (WMS) for display of maps in digital image format, Web Feature Service (WFS) for access of geospatial features and Web Coverage Service (WCS), devoted to data describing spatially varying phenomena (Lupp, 2008).

As an example, it is possible to address WMS (Web Mapping Service) standards, the same according to which the current WebGIS application project has been built. For WMS development, the Consortium suggests a simple base scheme (Fig. 3) and specifies how users should be capable of requesting a map as an output from the platform and which are the parameters that should be specified, such as the reference system in which the map will be drawn. Furthermore, different kinds of objects can actually be implemented through a WMS platform, according to the purposes of developers in terms of supported kind of queries and level of interactivity with the platform, e.g. static vs. dynamic maps (Carrion & Migliaccio, 2020).

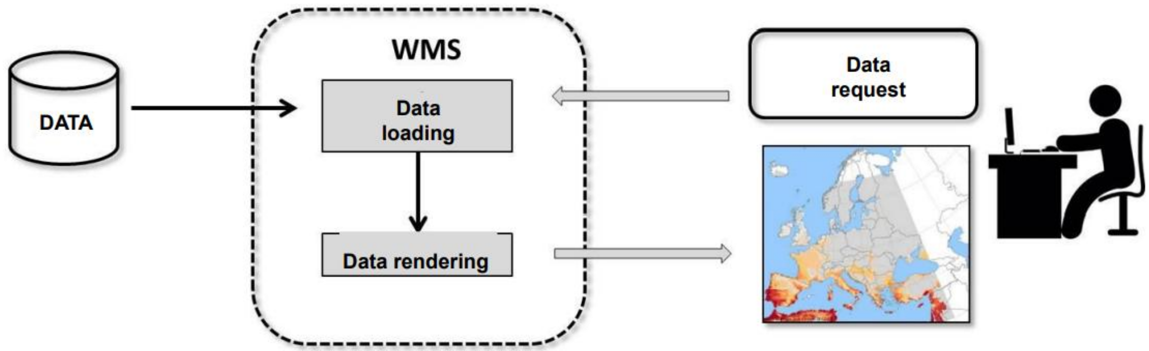

Figure 3: VMS functional scheme (Carrion & Migliaccio, 2020, p. 14).

3.2 Architecture in WebGIS

As introduced, WebGIS services represent powerful tools for the online analysis of geospatial data, providing several functionalities that can be exploited in different ways depending on users needs.

All of the capabilities of a WebGIS are actually deriving by the organization of the different components lying behind it, in a structured scheme, named architecture.

As a matter of fact different kinds of architecture can be built, according to the specific roles that the two main actors, client (user input) and server (processing and output generation), are meant to cover. In the following, the most spread schemes of architecture will be shown and briefly described, in order to provide to the reader an overview on the topic.

3.2.1 Thin client architecture

The simplest architecture style that can be analyzed is the thin client architecture (Fig. 4), which is characterized by small requirements on client-side, while the processing is deployed by the server in order to give back a response. Due to the fact that the client is not capable of directly reaching the GIS server, an intermediate role is played by gateway scripts (e.g. Common Gateway Interface, CGI) or equivalent programs, e.g. Java-based (Agrawal & Gupta, 2017). The main advantage of this structure is that client-side has no responsibility and the only needed resources are the ones related to request sending and displaying result. On the other hand, the full server-side control implies a relevant response time for processing and furthermore the functionalities in terms of client needs achievement are poor, forcing the client side to submit new requests also for basilar actions such as queries or zoom ones (Huang et al., 2010). This architecture style is also one of the oldest among available ones and application examples can be found since 90s (Putz, 1994).

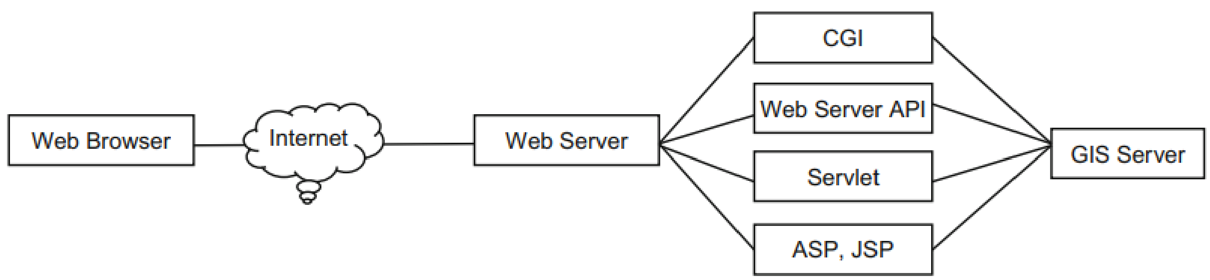

Figure 4: Example of thin client architecture for a WebGIS (Agrawal & Gupta, 2017, p. 5).

3.2.2 Thick client architecture

An evolution of the previously addressed scheme is the thick client architecture (Fig. 5), a more powerful organization in which the processing can be performed both server and client-side. This is possible thanks to the boost of browser's capabilities obtained by inserting in the architecture plug-ins, applets or other systems. The main advantage of this style can be highlighted as the possibility of performing small actions completely client-side, without the need of the server and running the client application also in case of no connectivity with the server itself (Agrawal & Gupta, 2017).

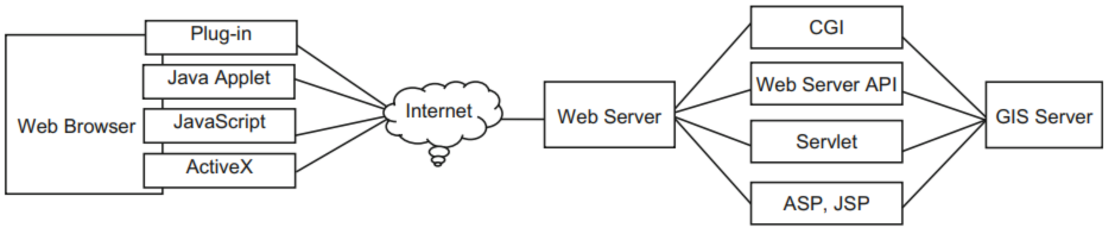

Figure 5: Example of thick client architecture for a WebGIS (Agrawal & Gupta, 2017, p. 5).

In addition, it can be stated that often thin and thick client architectures are combined in hybrid architecture, in order to take advantage of the most relevant characteristics of the two systems. Specifically, this integration will consent to split the contribution between the server-side, mainly in charge of performing data manipulation processes, and the client-side, devoted to user interaction tasks (Agrawal & Gupta, 2017).

3.2.3 Service-oriented architecture

Next analyzed architecture is SOA (Service-oriented architecture), which was built in order to solve problems related to the diverse nature of applications and information to be integrated within a system (James, 2010). Indeed, WebGIS services stand out from traditional web services for the presence of characteristic data formats, semantics, relationships and so on, resulting in complexities in terms of interoperability (Vescoukis et al., 2012).

SOA-integrated web services can have three distinct roles within the process: provider, broker (catalog) and requestor (user). All of them are characterized with implementation (specifying the provided service) and an interface, that can correspond to buy or sell category. In particular, a buy interfaced service will play the role of requestor, specifying the kind of service that is actually needed, while the sell one represents the producer role and specifies the available service that can be exploited (Van Der Aalst et al., 2007).

Through a set of structured kind of messages, web services related to this architecture are so able to communicate clearly (as in Figure 6 example), in a coherent way with their characterization, with the aim of improving the overall processing through the reduction of integration issues. The whole organization is clearly built following some base rules, devoted to increase functionalities, such as loose coupling principle (that allows to distinguish each web service and avoid reciprocal disturbances), interoperability, reusability, discoverability (related to the listing of available services) and governance (Agrawal & Gupta, 2017).

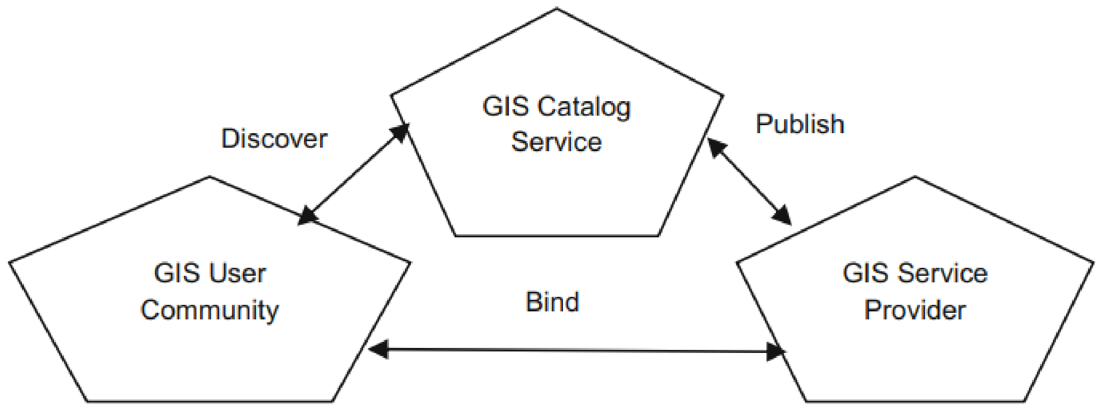

Figure 6: Example of service-oriented architecture for a WebGIS (Agrawal & Gupta, 2017, p. 7).

Several applications of SOA can be found in literature, in different field of interest; as an example it is possible to mention a study in environmental sciences, devoted to the detection and discovery of water data (Huang et al., 2011). SOA systems have then been reported as particularly suitable for GIS applications (and actually more efficient than traditional applications), thanks to their interoperable environment and to the ease of providing real-time information (Friis-Christensen et al., 2007). Furthermore, the workflow of this architecture consents a reduced waste of functionalities, because the system is capable of activating only the provision of services that are actually needed by the users.

3.2.4 Spatial cloud computing

Cloud computing is one of the most recent evolution of computing techniques, based on virtualization and SOA; in Figure 7 an example of architecture is shown. In this framework all the facilities, including software, platform and infrastructure, are provided through the Internet. The client (once the user has log on the system) can then make a request to the cloud for reaching the above-mentioned facilities. As an example, a client (thick, thin or mobile) is capable of asking the cloud for a specific action, such as geoprocessing of a dataset, that will be accomplished through the cloud itself, without the need of further participation of the client-side, as a sort of boosted virtual machine environment.

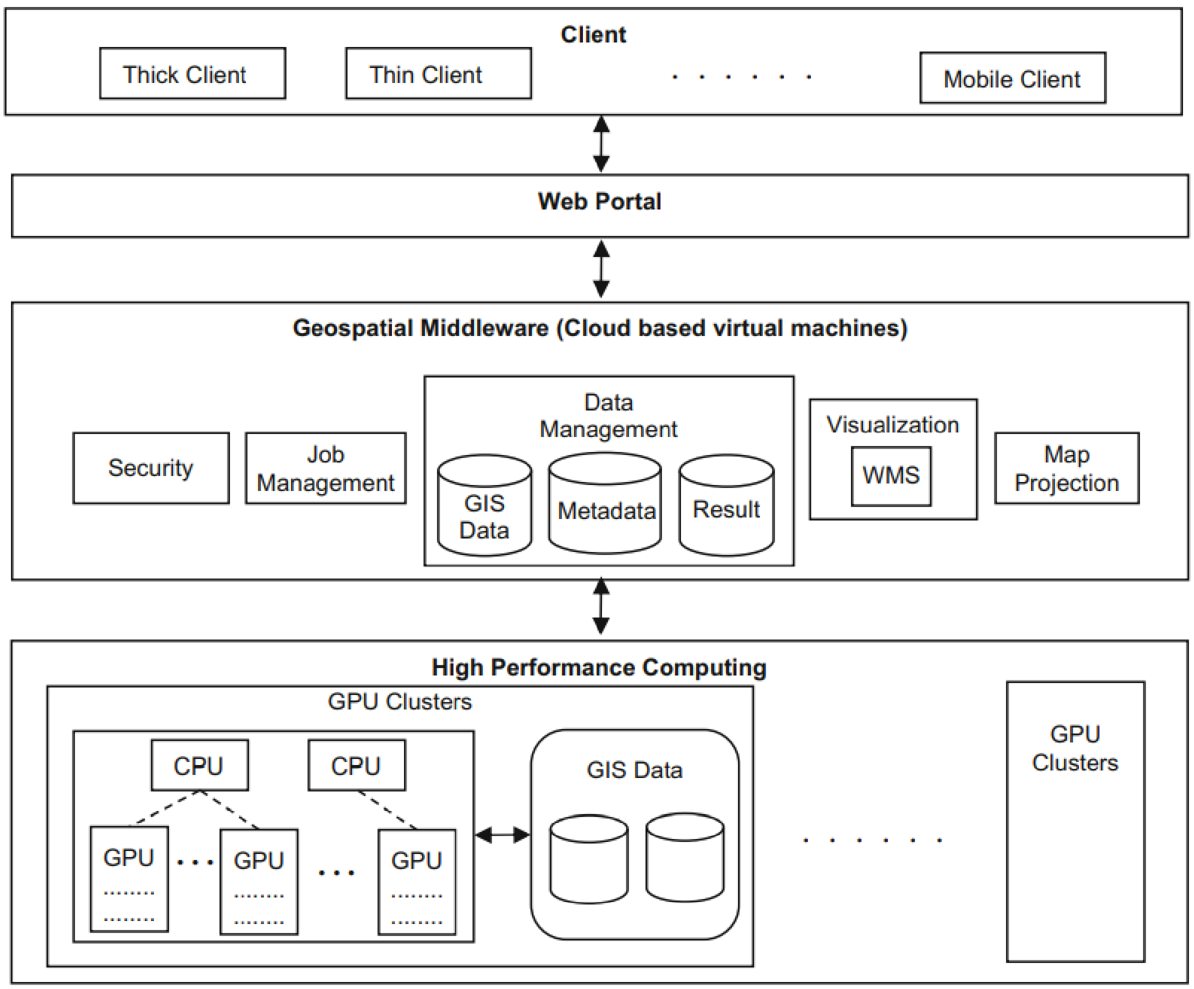

Figure 7: Example of spatial cloud computing architecture for a WebGIS (Agrawal & Gupta, 2017, p. 9).

Cloud-based processing allows the user to achieve great results, taking advantage of the relevant availability of resources and services that this kind of system can provide through the Internet. Furthermore, its "structure" enforces the sharing and communication aspects, leading to a very dynamic environment for users, characterized by ease in accessing data and by a greater flexibility and resources availability with respect to traditional instruments (Agrawal & Gupta, 2017).

It can be of interest to list some of the most spread and supported environment that employ cloud processing, i.e. Amazon EC2, Microsoft Windows Azure and Google App Engine (Zhang et al., 2010).

Lastly, it is relevant to state that this kind of system, even though quite recent, has already found a lot of different applications in practical GIS-related fields of work, covering different fields, among which massive data processing (Cui et al., 2010), flood monitoring (Kussul et al., 2012) and disaster management (Wan et al., 2014).

3.3 A practical issue: software property

Before proceeding with specific analyses of the architectural components, it could be useful to point out an important issue that has to be faced while building an application of this kind, related to the choice of the most suitable environment for a project development. In particular, next paragraph will be devoted to the discussion of software property topic.

Property is actually one of the most relevant features of a software, that characterizes its capabilities and usability within a certain application. Indeed, two main categories of software, and more in general environments, exist: the open (e.g. GeoNode) and the proprietary ones (e.g. ArcGIS). While the first are free to be employed by whichever user can download it, or in case of a web application to access a browser, the latter requires a specific license (usually obtainable for a fee) that, depending on its characteristics, can allow the user to accomplish some operations or to access the whole set of applications available in an environment. It should be also noticed that a proprietary software is usually characterized by a more intuitive interface and by the possibility of interconnecting in a quite simple way the different apps that the owner provides; in addition, working within a proprietary software guarantees a certain stability of the system and a clear set of information and tutorial specifically designed for helping users, jointly with an official customer assistance. On the other hand, it should be pointed out that an open-source software has its roots in a community of users and developers and that creates an active environment in which people can help each other in an effective way, sometimes even faster than a proprietary system can consent.

Anyway, the main clue of an open-source software is the possibility of customizing existing functions or creating new ones in a shape that it is as suitable as possible with respect to the user needs; obviously, to do this, a quite deep knowledge and some skills in coding are needed, but in case of an expert user almost any of the features of a proprietary software can be reproduced also in an opensource platform. It should be reminded, that a work developed by taking advantage of data or applications belonging to a certain opensource agreement should be preferably published in accordance with the same characteristics (Carrion & Migliaccio, 2020).

In consequence of this discussion, a couple of additional comments can be useful to avoid possible misunderstandings. First of all, it is important to specify that not all proprietary software are strictly related to the payment of a fee for their employment; indeed, several applications of this kind can be found (and are actually very used), one for all, Google Maps, which is free, but employable only for non-commercial applications (Google, 2020). In this case, the access to all the services provided by the company is free, but the data retrieved through it should be intended as private, in the sense that the owner holds the rights on them and so it could in principle deny the access to them or expressly request some guidelines to be respected in publication of project that use its systems.

Lastly, it could be of interest to stress the fact that employing an opensource platform doesn't correspond directly to the production of an object compliant with open standards. Actually, this may seem a trivial concept, but in author's believe, it could be useful to underline the distinction of these two similar terms that still refer to completely different aspects of a GIS. Moreover, it is possible to have private software-based project that are absolutely compliant with open standards requirements (related to the already mentioned convention on data sharing), as well as there can be projects developed within an opensource platform that still not respect some of the OGC prescriptions (Vennemann, 2008).

3.4 How to build a WebGIS

The current chapter aims to provide an overview on the necessary steps to be performed for achieving a fruitful publication of a WebGIS. In particular, as previously mentioned, this goal will require a structured architecture in which several components can be retrieved, each one covering a specific role within the process. In the following paragraphs the main aspects of the mentioned architecture will be discussed, along with some presented examples of suitable software for the different components and practical applications in the framework of existing project.

As it can be seen in the simplified scheme in Figure 8, two main parts can be recognized in the WebGIS architecture, the client-side and the server side; furthermore, it is possible to add a distinction regarding what the user is able to display on its screen, and so to directly interact with (usually called "user interface"), and what is not visible for the user and processes autonomously information (pure interest of developers), respectively named front-end and back-end.

In general, a WebGIS application is characterized by the already-mentioned coordinated employment of components, which can be summarized as follows:

- client side: Web Browser application, Desktop GIS application (optional);
- server side: Web Server, GIS Server, GIS Database.

Often, all of them are embedded in an unique platform that connects all the involved software and procedures.

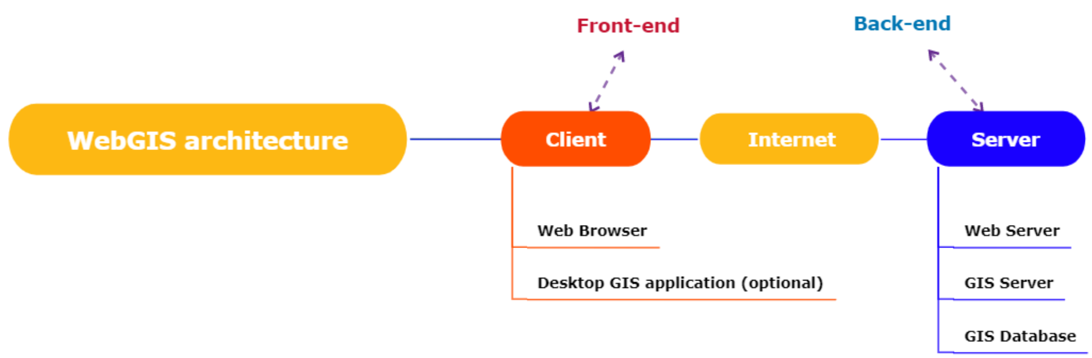

Figure 8: WebGIS simplified architecture (drawn by the author).

As mentioned before, the feasibility of integration of the different software components is a crucial aspect to be considered, in particular in case of opensource environments, that are based on synergies, sharing libraries in order to have a common framework that allows to easily manage the information among different components (Vennemann, 2008). In this regard, Table 1 shows some examples of interacting tools, classified with respect to the group (addressed as "Tribe") of belonging, some of which will also be quoted in the following discussions.

Tribe	Examples
C/C++ Tribe	MapServer, GRASS, Mapguide, QGIS, PostGIS, OGR/GDAL, PROJ4, GEOS, FDO
Java Tribe	GeoTools, GeoServer, uDig, DeeGree, JUMP, gvSIG
Web Tribe	MapBender, OpenLayers, Ka-map
.Net Tribe	SharpMap, WorldWind, MapWindow

Table 1: Examples of software involved in WebGIS architecture, classified in tribes (Vennemann, 2008, p. 6).

3.4.1 Web application

Coming to the analysis of single elements that constitute the architecture of interest, the first one to be addressed is the Web application.

It represents the complete user-side component of the WebGIS structure and it is usually coded in HTML language for what concerns the website, complemented with the use of CSS language for presentation of the HTML document (Lamanna, 2013).

A comment that can be proposed during the discussion of this kind of application is that actually two main categories can be considered: the ones working client-side and the ones mainly related to server-side. Despite the user interaction, that is obtained through web pages accessed via browser, the two groups are distinguished because of their way of operating. The first one performs elaborations client-side using specific languages such as PHP, while the second lies within the browser itself and takes advantages of DHTML and Javascript languages (Associazione italiana per l'informazione geografica libera - GFOSS.it, 2021).

Aiming to point out a software for each category, server-side can be represented by p.mapper (p.mapper, 2021), while OpenLayers (OpenLayers, 2018) can stand for client-side.

In detail, the latter is a powerful Javascript library, that has not particular requirements (e.g. no installation is needed) apart from a base knowledge of Java language; its potentialities are very wide and different levels of results can be reached with accurate coding. It allows the users to access several resources, both in terms of public geodata services (OpenStreetMap, Google Maps…) and data published through WMS and WFS services. It can be suggested for applications that do not need particularly advanced GIS functionalities, but still, if integrated with other tools such as MapServer (Open Source Geospatial Foundation, 2021), complex analyses can be achieved.

On the other hand, p.mapper requires to be installed on server, it is provided with an efficient user-interface and, most important, it can be exploited without the need of coding. Some disadvantages can anyway rise from the necessity of installing and configuring it (e.g. with reference to folders-path setting). In this case, as mentioned, a server support is needed and the most fitting combination remains the one with MapServer, for which the PHP MapScript (Open Source Geospatial Foundation, 2021) extension is required (Associazione italiana per l'informazione geografica libera - GFOSS.it, 2021).

When building this kind of application, the developer can design the whole user-experience, establishing which features of the website will be available and how the user will interact with the platform through its local terminal. Obviously, a relevant aspect to be considered is the accessibility of the system to the appropriate class of users, trying to develop an interface as user-friendly as possible, compatibly with the complexity of the service that will be given. In this way, it appears clear that different applications with different levels of difficulty can be developed, e.g. for newbie users (that maybe will only need simple processing) or advanced ones (in this case, a more complex application can be accepted, if that means having a more powerful tool).

Lastly, depending on the kind of final services to be provided, a suitable structure should be chosen for the website, in order to enhance its capabilities in an efficient way; two of the most common frameworks in this field will be presented as an example. If the project goal is mainly based on consulting and making queries on a map, or more specifically on a geographically defined area, then a good solution might be the implementation of a single-page web application, in which the principal subject is the map itself, with the possibility of displaying several layers, as it can be seen in Risk Data Hub map visualizer, powered by the Java application MapStore (Fig. 9). On the other hand, if the application would be oriented to the creation of a repository in which several datasets are stored, freely to be consulted and displayed on a map on the base of users' needs, a multi-page environment could result more efficient, as exemplified by Figure 10 with respect to a WebGIS for water analyses in Lombardia Region (BrianzAcque et al., 2020); multi-page approach was also chosen for the development of the GeoNode platform implemented for the current thesis, that will be deeply described in chapter 8.

Figure 9: Example of single page application, from Risk Data Hub project online map visualizer (Joint Research Center, 2020).

Figure 10: Example of multi-page application, from Lombardia region water analyses WebGIS (BrianzAcque et al., 2020).

3.4.2 GIS and Web Server

The other main actor of client-server architecture (in the back-end) is obviously the server, that is responsible of the elaboration of procedures requested by the client and of their responses. Then, another key component of the system is a software application in charge of putting the client in contact with the server on which appropriate data are stored (the ones related to the intended website), so to satisfy the initial request and let the user receive the expected response. This kind of application takes the name of Web Server and it can be considered to be part of the server itself (Laravel, 2019). In addition to this, a WebGIS platform is characterized by the need of another element capable of targeting specifically geospatial data and carrying out their peculiar processing, hence the name GIS (or Map) server. Its role within the architecture is directly devoted to the management of geospatial data and the provision of compatible services, such as WMS and WFS, and it is furthermore responsible for several GIS functionalities (editing, routing, object tracking, etc.), (Agrawal & Gupta, 2017).

Regarding GIS Server it is important to state that a large number of WebGIS projects relies on GeoServer environment (GeoServer, 2021), an opensource server devoted to geospatial data sharing. It can be installed both as a standalone application (requiring a Java Virtual Machine) and as application supported by Tomcat Web Server (The Apache Software Fundation, 2021).

GeoServer strong point is the interoperability granted by the use of open standards (GeoServer, 2021), that leads to an easy and quick publishing of WMS and WFS services. This aspect consents a fruitful integration with all platforms using the same rules, as mentioned above, whether opensource themselves (such as GeoNode) or based on proprietary software. In this regards it is meaningful to state that ESRI systems can be integrated with GeoServer, but even complemented by other servers (available on license) capable of boosting the system potential towards more complex operations, just like real-time visualization of geospatial data through ArcGIS GeoEvent server (ESRI, 2021) or deeper big data processing through ArcGIS GeoAnalytics server (ESRI, 2020).

A second example of wide-spread GIS Server can be represented by the already mentioned MapServer; it is actually more complex to be installed and used with respect to GeoServer, due to the need of knowing its specific syntax. Anyway, it can rely on a great programming interface, that allows the developer to interact with the server in different languages (PHP, Python, Java…). This aspect in particular consents the customization of the system up to the achievement of very advanced GIS functionalities, e.g. detailed queries and attributes analyses; in addition, the mentioned syntax (especially for Mapfile) allows the user to access and manage data in a simple way (Associazione italiana per l'informazione geografica libera - GFOSS.it, 2021).

However other additional cases deserve to be mentioned, starting from QGIS Server, that works with an external Web Server (e.g. Apache) and it is capable of offering a simple environment, actually similar to the Desktop application one, characterized by the presence of a single standardized language for all its components (QGIS project, 2014), a very attractive feature for users. Another kind of technology is instead the main core of Google Earth, a system that provides access to satellite images and allows geospatial analyses on them by unique Javascript algorithms that develop the whole procedure server-side, in cloud (as described in architecture paragraph), decreasing significantly the amount of time needed for each operation (Carrion & Migliaccio, 2020).

As far as the Web Server is addressed, it should be noticed that the selection of the most appropriate environment directly derives from the adopted combination of client application and GIS Server. One of the most common is the already mentioned Apache (The Apache Software Foundation, 2021), an application that can be installed locally and that allows to build and perform operations even without the need of a web hosting.

It could be of interest to list the schemes that can be obtained by integrating the open-source software mentioned in the previous discussion, as in the following (Associazione italiana per l'informazione geografica libera - GFOSS.it, 2021).

- OpenLayers only: it is sufficient to provide it with a server for HTML publishing or with a base Apache;
- GeoServer + OpenLayers: Tomcat or another Java container, so to be capable of using the Java GIS Server;
- MapServer + p.mapper: Apache with PHP support (to be able of using MapScript and as a consequence p.mapper);
- MapServer + OpenLayers: Apache.

3.4.3 GIS Database

A crucial part of the infrastructure is clearly the one through which the geospatial datasets can be accessed so to be processed in WebGIS: the GIS Database. During the decades, different kinds of data organizations were built and used, such as hierarchical and network models. In the last forty years, anyway a more consistent model was developed and applied, aiming to solve the issues related to the lack of data independency in older schemes, that took the name of relational model. It is mainly based on the concepts of relations and tables, which are able to connect data following a logic path. This leads to the most important characteristics that allowed the overcoming of past models, that is the possibility for users to address data only knowing what they are looking for and not how the data itself are stored in physical terms (Ceri et al., 2014).

Each information available through the model is characterized by a univocal codification for each entity and by the design of tables, as exemplified in Figure 11. In particular, this kind of solution is not used only for describing objects (or entities) and correlate them, but also the specific relations among them are described through tables. In this way, the relations themselves become a further element that can be characterized individually and, obviously, associated with the corresponding entities that they are meant to link.

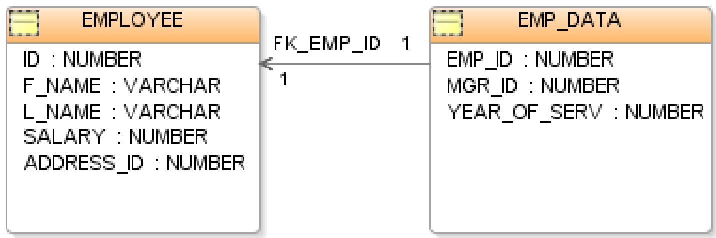

Figure 11: Example of table relating two entities (AA. VV., 2011).

All these sets of information are managed during the implementation phase through the use of codes or, more properly, keys. In practical terms, as it was stated before, when interrogating the database using a software connected to it, it will be sufficient to make a query for what the user is looking for, independently on how the object is archived (Migliaccio & Carrion, 2020).

In Figure 12 an example of relational model database coming from a real WebGIS project is presented.

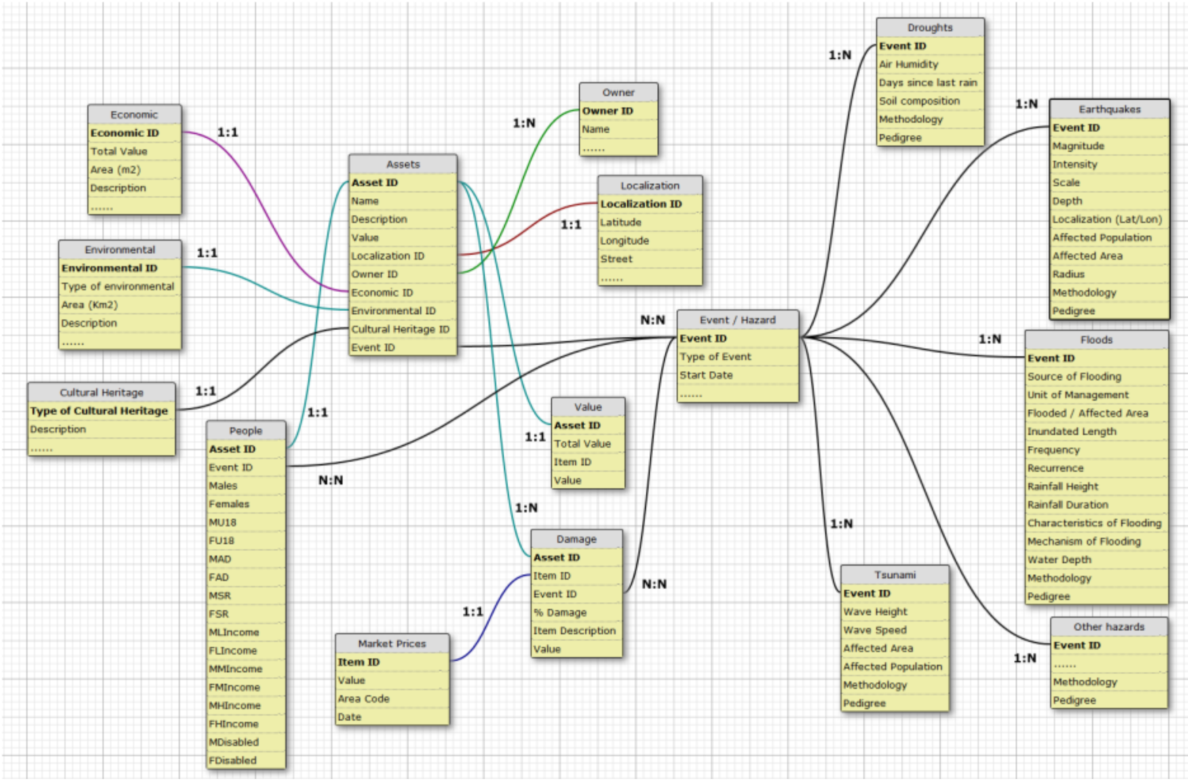

Figure 12: Example of a relational model for databases, from JRC Risk Data Hub project (Díaz & Ferrer, 2018, p. 27).

As a matter of fact, it can be stated that among the different versions of relational databases, the most used is the so called object-oriented model. This represented a sort of step further in terms of implementation, towards the possibility for users not only to take advantage of the accessibility of a relational database, but also to expand it. In particular, among the innovative aspects of this structure it is possible to find the integration of nested objects and the definition of user-defined data types, whose integration leaded to a higher level of customizability of the system, consenting implementations way more efficient and specifically built for each user project (Stajano, 1995).

The achievement of database implementation into a system is performed through the structuring of a DBMS (Data Base Management System), a set of software working together and in coordination with other programs in order to let the user access, explore and make use of the archived datasets.

The main components of a DBMS can be listed as follows (AA. VV., 2011):

- DBMS engine;
- Data definition sub system;
- Data manipulation sub system;
- Application generation sub system;
- Data administration sub system.

Aiming to summarize the principal characteristics of DBMS, it is possible to state that these structures allow to consider data as a common resource for an organization (e.g. a company), shared and available for all its components (coherently with internal regulations and permissions). Furthermore, the DBMS organization provides a unified and precise model of the analyzed context, constituting a strong base for operations, both current and future ones. It is important to mention that obviously a DBMS can be integrated also after its introduction in a system, not only in terms of contents added to the database, but also in data management aspect, with the aim of guaranteeing an updated tool, as suitable as possible to the needs of users. Lastly, data independence within a DBMS, that is a fundamental characteristic, enforces the development of flexible and easily modifiable applications in which data can be integrated.

For the sake of completeness, when developing a DBMS a couple of negative aspects should be taken into account as well. Firstly, it is important that all services (components) within the DBMS are available at the same time, because it is not easy to separate the actually required ones from the others and a procedure of this kind could result in impairment of the system functionalities. Secondly, it should be considered that DBMSs are complex platforms that require a certain amount of money to be developed and also implemented, due to the necessity of specific training for users who have to directly interface with them (Ceri et al., 2014).

Regarding available software for achieving database management in a WebGIS environment, it should be said that even if several ones are available (CSQL, Microsoft SQL Server, Oracle Database, etc.), the most spread application is PostgreSQL (The PostgreSQL Global Development Group, 2020). It is actually organized as an object-relational database, that makes a step forward with respect to traditional relational model, incorporating four additional basic concepts (classes, inheritance, types and functions) in order to give a more structured shape to the datasets and avoid possible problems in processing that historically have been recognized in classic Relational applications due to their extreme simplicity.

PostgreSQL is usually complemented with PostGIS (PostGIS Project Steering Commitee, 2021), another service that enhances the database capabilities, by adding support for geographic objects and several features, among which improvement in managing data coming from ESRI environment or other third party, raster processing and rendering and the possibility of performing 3D analysis through dedicated tools. It is relevant to mention that both software are open-source and compliant to Open Geospatial Consortium guidelines.

3.4.4 Advanced development: the Docker containers system

A further development of a WebGIS architecture is represented by the implementation within the system of a recently developed application, called Docker (Docker Inc., 2021).

This tool aims to empower development of applications, through the integration in the studied system of a docker-containers environment, characterized by the subdivision of the system itself into separate containers. Quoting the official Docker website "A Docker container image is a lightweight, standalone, executable package of software that includes everything needed to run an application: code, runtime, system tools, system libraries and settings." (Docker Inc., 2021).

Each of the single units constitutes an independent computing environment, in which software code and all its dependencies are moved and singularly run. The exchange of information among different containers is easily achievable, so that even though each of them is working separately, the overall process is not affected negatively, ensuring processing uniformity.

This results in an improvement of development, allowing to analyze separately all the different components of the system, also in term of single processes, performing operation on a specific part without conflicting with other ones and carrying out intermediate checks of the desired functionality. Furthermore, if needed, the developer can decide to switch off one single container and operate in a lighter framework.

Docker features are so capable of simplifying development and usability (through the use of a standardized coding language) and boost the sharing of platforms built in this environment (AWS, 2021).

The Docker application can be downloaded for free for personal use, but a more complete version for professional developers is available too, with more advanced functionalities. In addition, the Docker team itself is directly involved into the development of opensource applications, making necessary components and tools available for everyone who is working on a project in which the application can be integrated, if requested; the goal is to support an array of projects in order to continuously enforce evolution of the containerization movement

(Docker Inc., 2021). Lastly, it can be mentioned that Docker system is provided both with a Desktop application suitable for several Operative System, but also through a cloud-based hub in which several existing geospatial applications can be retrieved (Nüst, 2016).

The Docker system is at the present moment integrated into different GIS-related applications, such as the open-source Geocontainers (Geocontainers, 2021). This project goal is to support geospatial web services and applications, with specific reference to the usability of Docker approach in this field. In particular, the integration into a GIS environment is reported to be very fruitful, in terms of fastness in building the applications and the possibility of perform during development is addressed as one of the main features of the system integration (Geocontainers, 2021).

3.4.5 Desktop GIS application - optional

Even though the most interesting aspects of a WebGIS is the possibility of operating (on different levels, of course) without a specific knowledge on GIS systems and, most of all, without having installed a GIS software in the terminal, expert users may take advantage from the integration of the two systems. Indeed, if data are available to be downloaded, the local GIS allows to perform geospatial processing without internet connection and often it is able to support more complicated requests than a WebGIS.

In this framework an advanced user will be capable of downloading geodata from the Web platform and manage them locally for its own goals or, vice versa, specific datasets can be arranged locally and then be shared to the platform, in order to be available for other users in a collaborative workflow. As mentioned before, also in this case, there will be differences in operations (and in general in terms of usability) depending on the specific software and most of all on its category, opensource (e.g. QGIS, GeoNode) or licensed (e.g. ESRI environment and applications such as ArcMap and ArcGIS Pro).

Actually, these processes are not related with the publication phase of the WebGIS framework, that is why the current paragraph reports them as optional. Anyway, it is relevant to stress the fact that usually the employment of Desktop applications leads to better performances, at least in results graphical aspect. Furthermore it is necessary to highlight that the combined use of WebGIS platform with a desktop application could be a fruitful tool for experts technicians looking for more complex results, while the interests of common users are totally achievable through the WebGIS itself.

3.5 Architecture examples derived from existing projects

As a conclusion, in this paragraph a series of examples of implemented WebGIS architectures will be shown. The aim is to provide a brief comparison among some real project, in order to perform a partial assessment of software choices by developers. Obviously, the small number of considered examples cannot allow to a completely satisfactory analysis, but some interesting comments can be anyway pointed out.

- Figure 13: Spatial database for medieval fiscal data in Southern Italy project, combining Apache, QGIS Server, PostgreSQL-PostGIS server side and Java app in client-side;
- Figure 14: Risk Data Hub project - GeoServer (GeoNode environment), PostgreSQL-PostGIS, MapStore (Java) app;
- Figure 15: SIMILE project - scheme of the first container (Docker approach) - GeoServer (GeoNode environment), PostgreSQL-PostGIS, Django interface;
- Figure 16: SITAR project – GeoServer (GeoNode environment), PostgreSQL-PostGIS;
- Figure 17: EU-LULC project - GeoServer (GeoNode environment), GeoTIFF-PostGIS, Leaflet library;
- Figure 18: Indonesian land use monitoring project – ArcGIS Server, PostgreSQL-PostGIS, Tomcat Web Server;
- Figure 19: Water resources monitoring project in Burkina Faso - GeoServer (GeoNode environment)/MapServer, PostgreSQL, OpenLayers, GRASS.

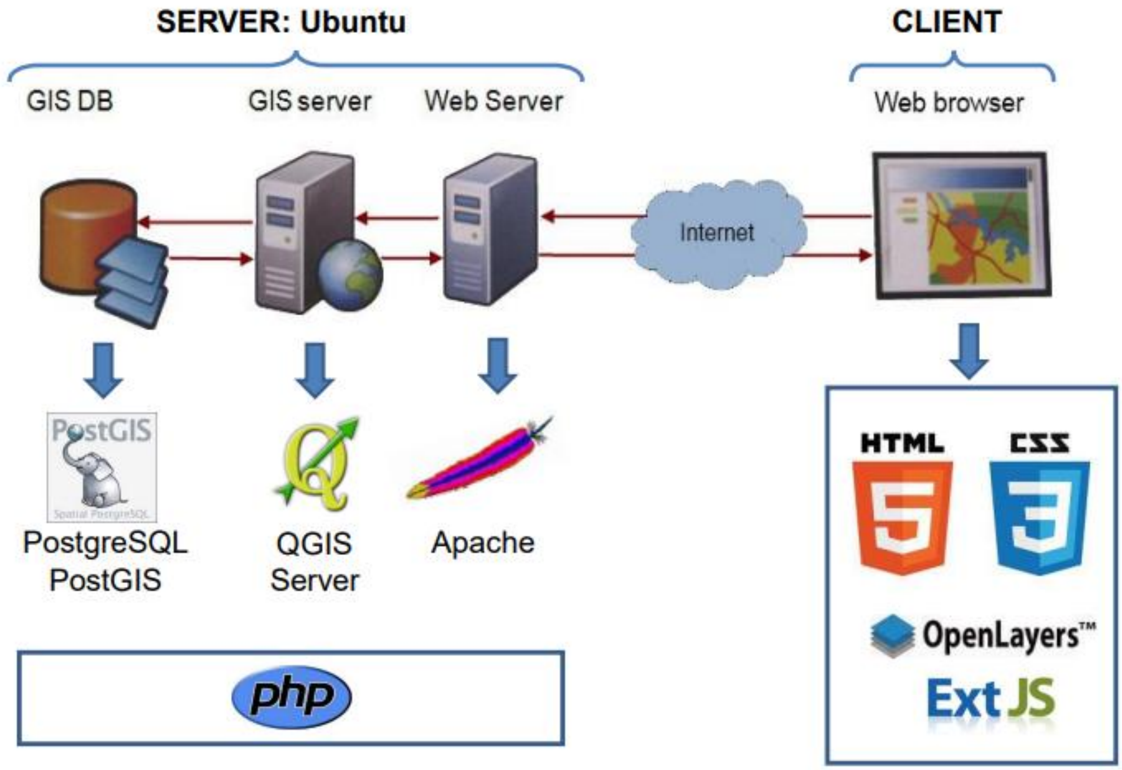

Figure 13: Example of WebGIS application architecture, from Spatial database for medieval fiscal data in Southern Italy project (Carrion et al., 2015)

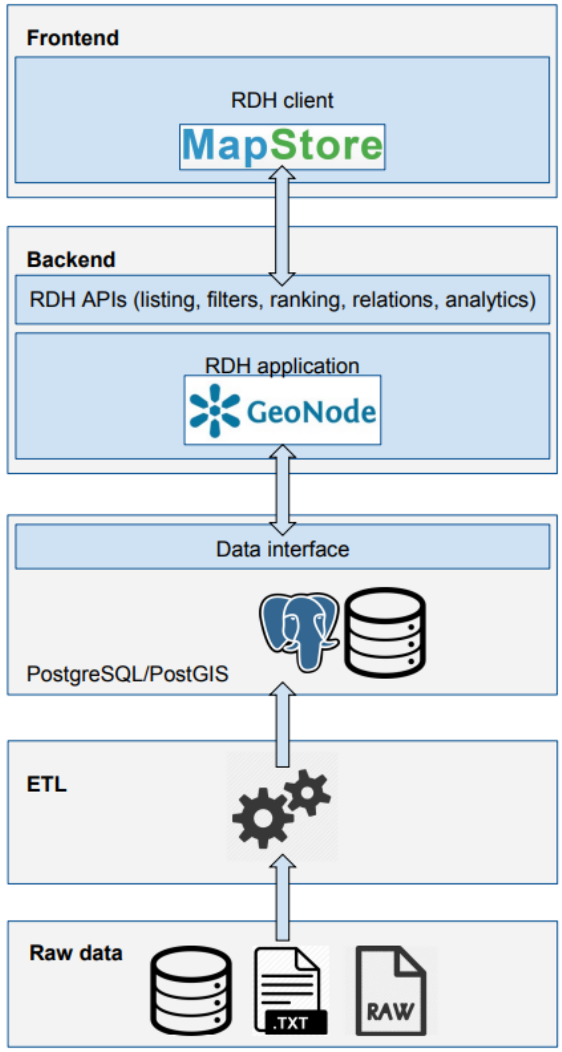

Figure 14: Example of WebGIS application architecture, from Risk Data Hub project (Antofie et al., 2019, p. 11).

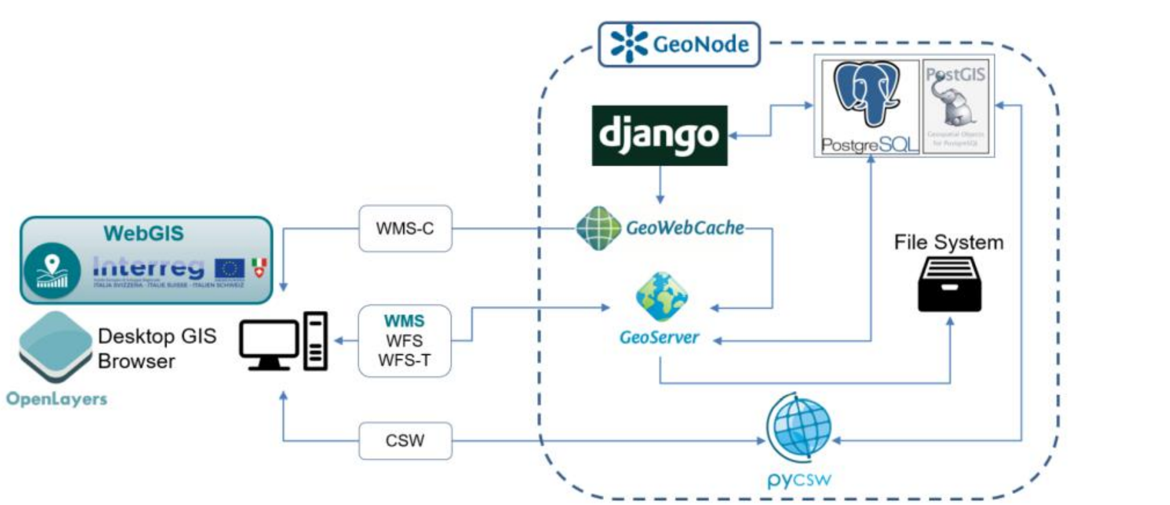

Figure 15: Example of WebGIS application architecture with Docker integration, from SIMILE project (Toro et al., 2021, p. 3).

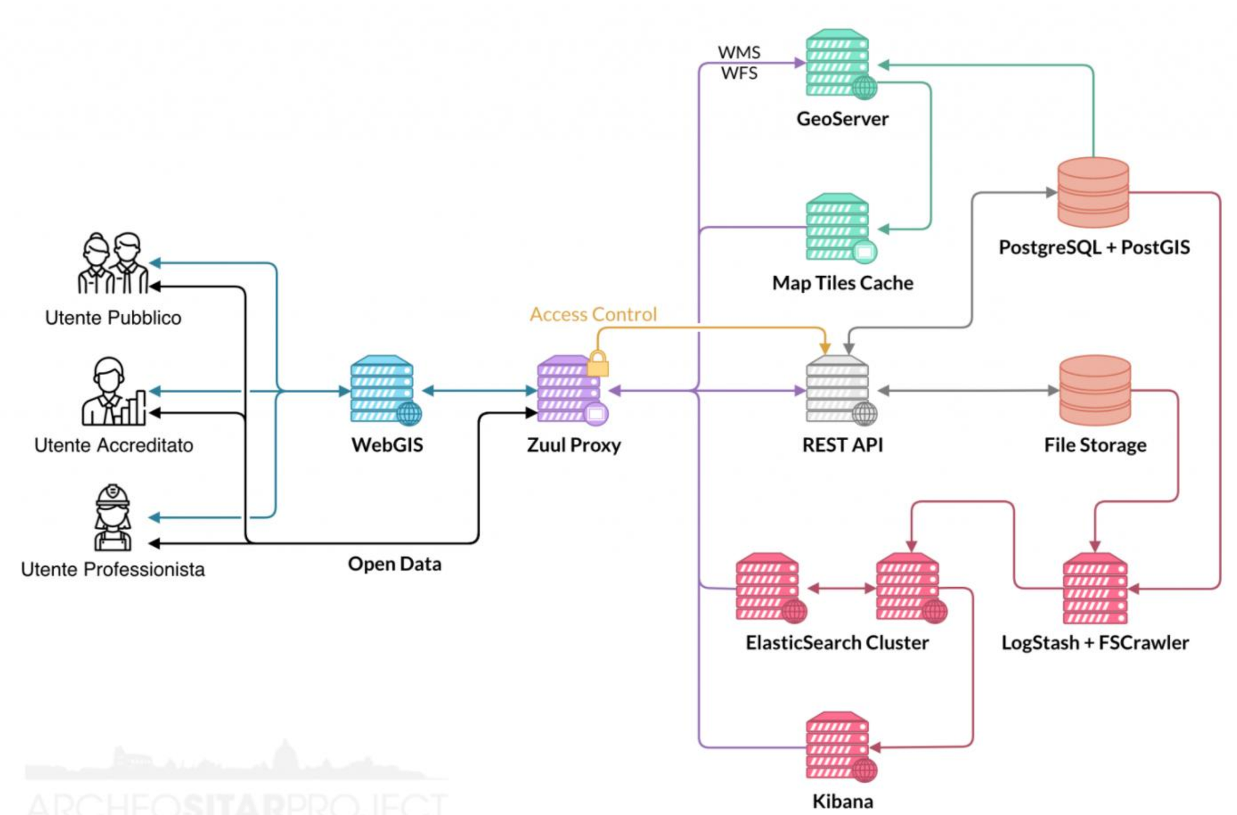

Figure 16: Example of WebGIS application architecture integrated in a complex environment, from SITAR project (Archeo SITAR Project, 2020).

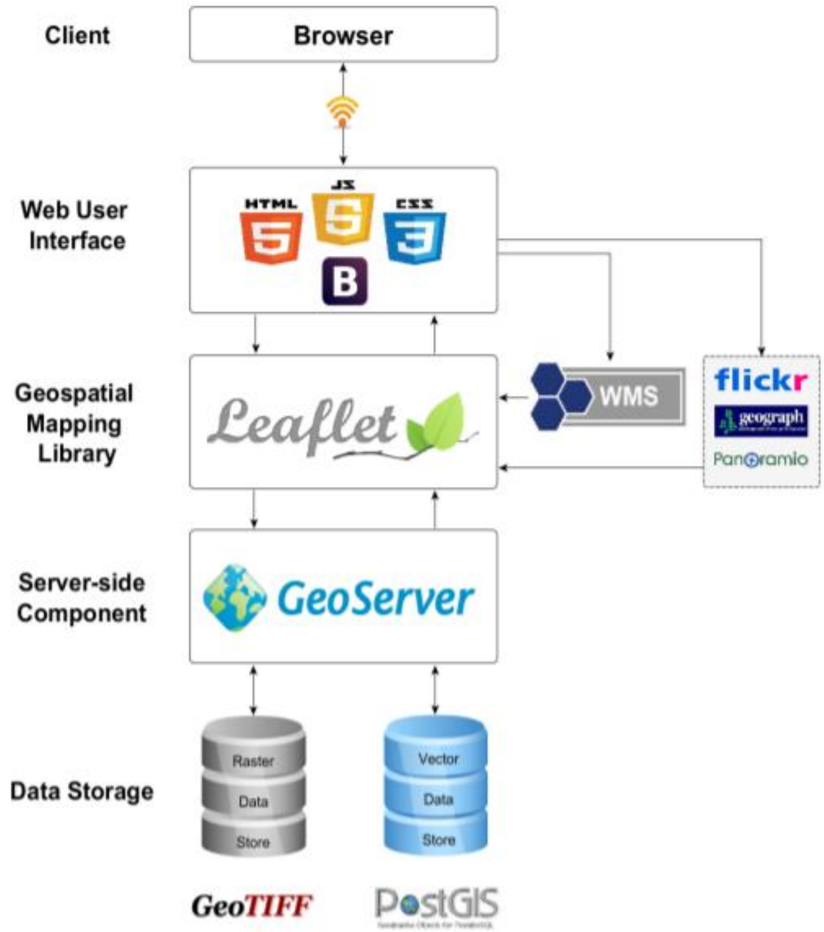

Figure 17: Example of WebGIS application architecture, from EU-LULC project (Brovelli et al., 2016, p. 3).

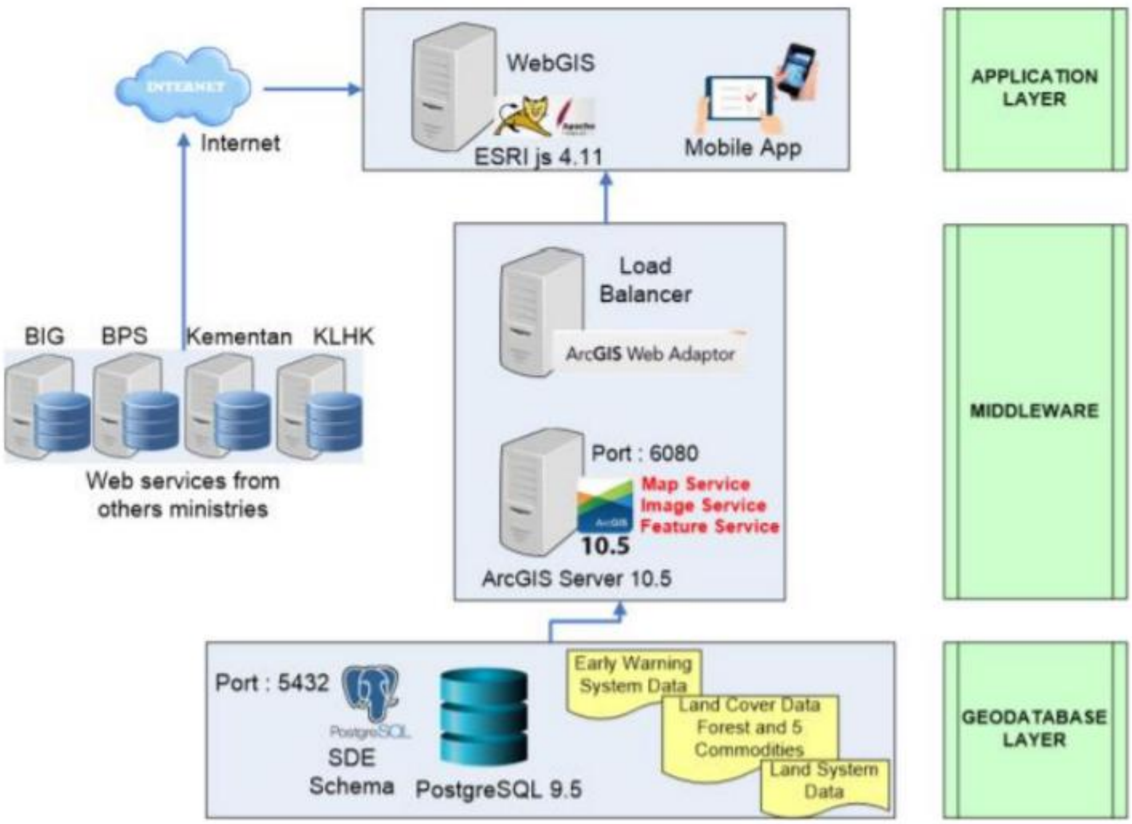

Figure 18: Example of WebGIS application architecture, from Indonesian land use monitoring project (Purwonegoro et al., 2021, p. 5).

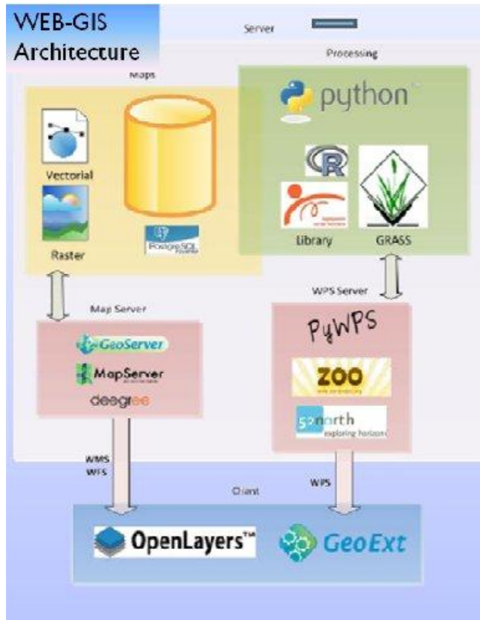

Figure 19: Example of WebGIS application architecture, from Water resources monitoring project in Burkina Faso (Ciervo et al., 2011).

Aiming to compare the listed architectures, the first comment to be provided is the one regarding the differences of context of implementation, which is actually representing the wide variety of field of application for a WebGIS. Then, it should be said that the complexity of comparisons is increased by the non-coincident structure of schemes regarding the different projects, but anyway some results can be observed.

First of all, it appears clear the great diffusion of PostgreSQL-PostGIS combination with respect to DBMS, as expected and pointed out also during theoretical databases discussion. On Web Server side, different employed software can actually be recognized, among which the previously introduced Apache and Tomcat software (still belonging to Apache framework).

GIS Servers too seems to be quite differentiated among the presented projects, with the presence of a case for each QGIS Server and ArcGIS server; nevertheless, the great majority of the selected architectures are mainly based on GeoServer (and so, GeoNode) environment, often combined with MapStore or other Java applications. This result too was expected, considering the actual spread of this platform and it is once more supporting the choice of GeoNode for the development of the current thesis WebGIS platform.

Lastly, a final consideration can be devoted to the integration of Docker containers system into a WebGIS that can be individuated in SIMILE project (Toro et al., 2021). The designed application is composed by two main platforms built into separate containers, one devoted to allow geodata sharing in GeoNode environment, the other specifically meant as a standard WebGIS and developed in Java. Although they're separated and separately developed, the interoperability of the two applications is granted by the common use of OGC standards, leading to a clearly structured and complete platform made of two applications working as one. It is possible to correlate the poor diffusion of this tool among the selected projects with statements on the fact that Docker system is a relatively new one and so it is not yet well known or simply to the more complex and advanced approach that its employment would require.

4. Geographical contextualization and site characterization

Hydroelectric power is the main renewable source of energy in Italy, corresponding to 41% of the total electric supply (We Digital Magazine, 2021). This means that thousands of water bodies, natural or artificial, are exploited for energy production through dedicated dams systems. Among the 538 Italian “relevant dams”, intended as maximum priority assets, 73 are located in Lombardia region, including Ponte Cola one in Gargnano municipality, Brescia province, which is the study case of the current thesis.

Following the directive *Indirizzi operativi inerenti l’attività di protezione civile nell’ambito dei bacini in cui siano presenti grandi dighe* (Presidenza del Consiglio dei Ministri, 2014), enacted by Italian Prime Minister, each of these structures must be provided with a specific document, called *Piano Emergenza Dighe* (Dams Emergency Plan, it will be addressed as PED) to be issued by the regional authority, containing detailed information about dam interaction with territory and Civil Protection measures to be activated in case of need. Specifically, the plan focuses on two main aspects that are territorial framing and operational planning, complemented with useful documents available as attachments to the official one. Furthermore, PED can be recognized as mainly addressed to activation of interventions and emergency management, trying in this way to connect pre-event phase (devoted to increase the preparedness) and the response one.

Obviously it should be developed in an interdirectional and interfunctional framework, involving institutions, Civil Protection and experts in order to define possible scenarios and to establish the most suitable responses in terms of emergency management.

Actually, the plan is aimed at being prepared in case of a great emergency such as a dam break, but also at facing possible dangerous conditions including ordinary technical maneuvers that can affect downstream hydraulics (Regione Lombardia, 2020).

Ponte Cola plan was published in June 2020 and, even if due to COVID-19 pandemics, it was not possible to perform simulations of its implementation, it is one of the first cases of complete and approved PED.

4.1 Dam and watershed characteristics

Ponte Cola dam is situated (Fig. 20) in northern Italy, in the mountainous area between Garda and Idro lakes, belonging to Gargnano municipality (Brescia province),more specifically in the area delimited by M. Caplone (1977 m), M. Cingla (1669 m), M. Alberelli (1167 m) and M. Magno (1045 m). The dam intercepts Toscolano stream along its course towards Garda, originating an artificial water body (almost 52.25 x 10^6 m^3) that takes name of Valvestino lake.

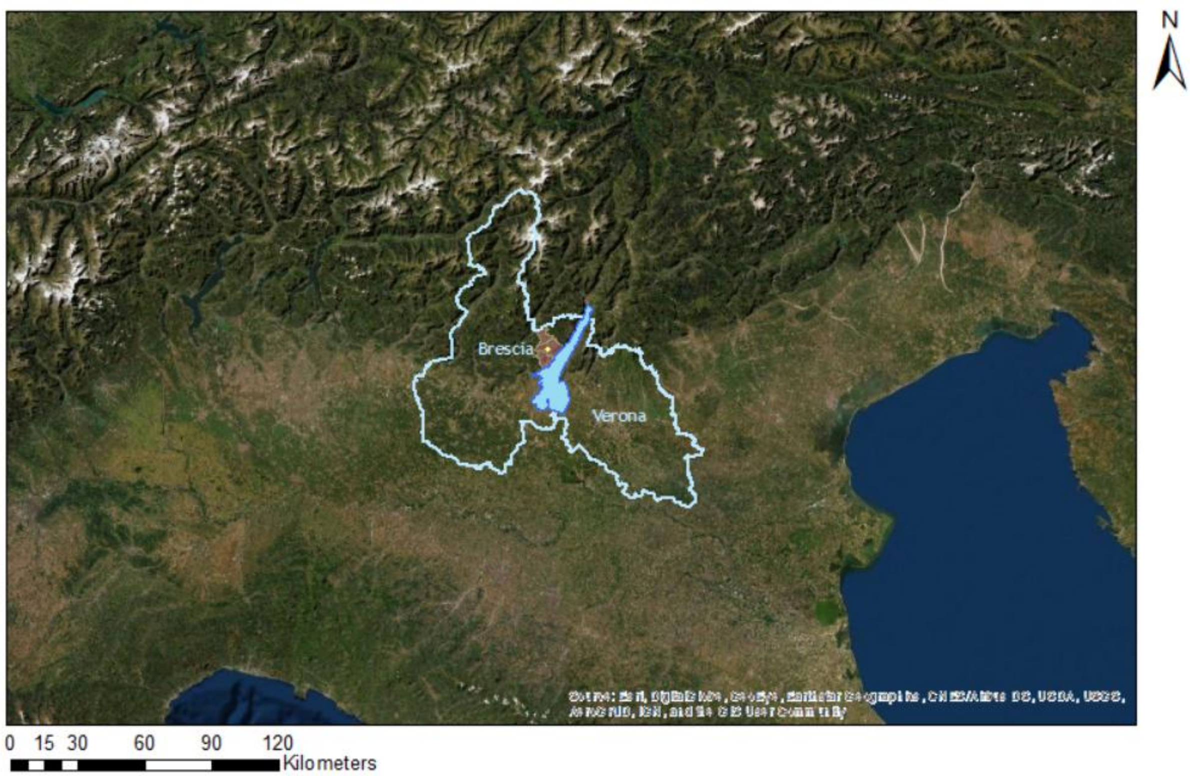

Figure 20: Geographic contextualization of the study area.

The structure (Fig. 21) is made of a double curvature concrete arch insisting on the mountain gorge. Its main scope is hydroelectric one, accomplished by combining flow rates coming from two different watersheds, with an average altitude of 927 m above sea level; the principal one corresponds to Toscolano hydrographic catchment and it covers a surface of almost 100 km^2, while the other is associated to San Michele torrent in the adjacent valley, connected to Valvestino through an open channel flow. Furthermore, thanks to the mixed pump system of the dam, water can even be raised from Garda lake and stored into the basin, creating a sort of hydraulic energy stock.

Figure 21: Ponte Cola, watershed and dam body detail (ProgettoDighe, 2021; GDB, 2020).

Several details about the dam can be noticed in Table 2, among which two values for maximum water level, the first one related to the actual reservoir capacity (503 m), while the second represents the allowed level, established as a consequence of foundation rock and hydraulic tests performed in 2003.

Dam's name	**Ponte Cola**	Archive N. *D.G. Dighe*	760
Municipality in which the barrage is located		Gargnano	
Province		Brescia	
Region		Lombardia	
Retained stream		Toscolano torrent	
Downstream water		Garda lake/Mincio river	
Hydrographic catchment		Po river	

Construction period	1962 – end of construction; 1963 – testing
Dam typology (point B.2. D.M. 26/6/14 or previous norm)	Ab3 – curve concrete dam, dome shape
Dam height (as per L.584/94)	122.0 m
Reservoir volume (as per L.584/94)	52.25×10^6 m^3
Main use	Hydroelectric
Managing Body	Enel Green Power Italia Srl
Reservoir state	Limited
Surface of directly subtended hydrographic catchment	97.25 km^2
Surface of connected hydrographic catchment	24.58 km^2
Flood control level (FCL)	503.00 m above s.l.
Exceptional flood level	504.00 m above s.l.
Limitations due to safety measures	
Allowed water level	480.00 m above s.l.
Allowed water level in case of flood	483.00 m above s.l.
Allowed water volume	26.62 Mm^3
Characteristic spillways discharge	
Maximum flowrate from surface spillway (in FCL)	152 m^3/s
Maximum flowrate from middle spillway (in FCL)	107 m^3/s
Maximum flowrate from depth spillway (in FCL)	87 m^3/s
Maximum flowrate from middle spillway (in allowed water level)	91 m^3/s
Maximum flowrate from depth spillway (in allowed water level)	80 m^3/s
Qmax – maximum flowrate in downstream riverbed	38 m^3/s
Qmin – threshold for spillway flowrate	15 m^3/s
ΔQ – incremental limits	5 m^3/s

Table 2: Technical information on Ponte Cola dam, translated from *Documento di Protezione Civile della diga di Ponte Cola* (Prefettura di Brescia, 2019, p. 3).

On downstream side, the riverbed covers a distance of about 10 km between the dam body and Garda lake. According to Italian regulation, a standard flowrate is discharged from dam's bottom spillway 400 m downstream and later on is incremented by some lateral streams flowing into the torrent that then is newly intercepted and deviated to another hydroelectric plant located some kilometers away. The stream traverses mainly steep valleys characterized by bare rock or poorly vegetated areas, while in the last 2 km it crosses the largest settlement of the area, Toscolano Maderno, splitting it into two sides (Regione Lombardia, 2020, pp. 9-14).

4.2 Potentially involved municipalities

Toscolano Maderno is not the only municipality of the zone to be exposed to possible water release. Indeed, simulations of flooded areas show that also Gargnano town could be affected and, more in general, the plan considers as a reference territory (Fig. 22) even all settlements along the riverbed interested by the presence of Ponte Cola dam, so the ones (upstream and downstream) that are located within a distance of 10 km from the confluence of the stream into a bigger waterbody; this last definition includes also Valvestino municipality. Furthermore, it should be pointed out that in case of dam break the wave entering into Garda lake could propagate and create problems also on the opposite side of the lake, so in order to have a complete emergency system, also Veneto region (and Verona province) contribution is necessary.

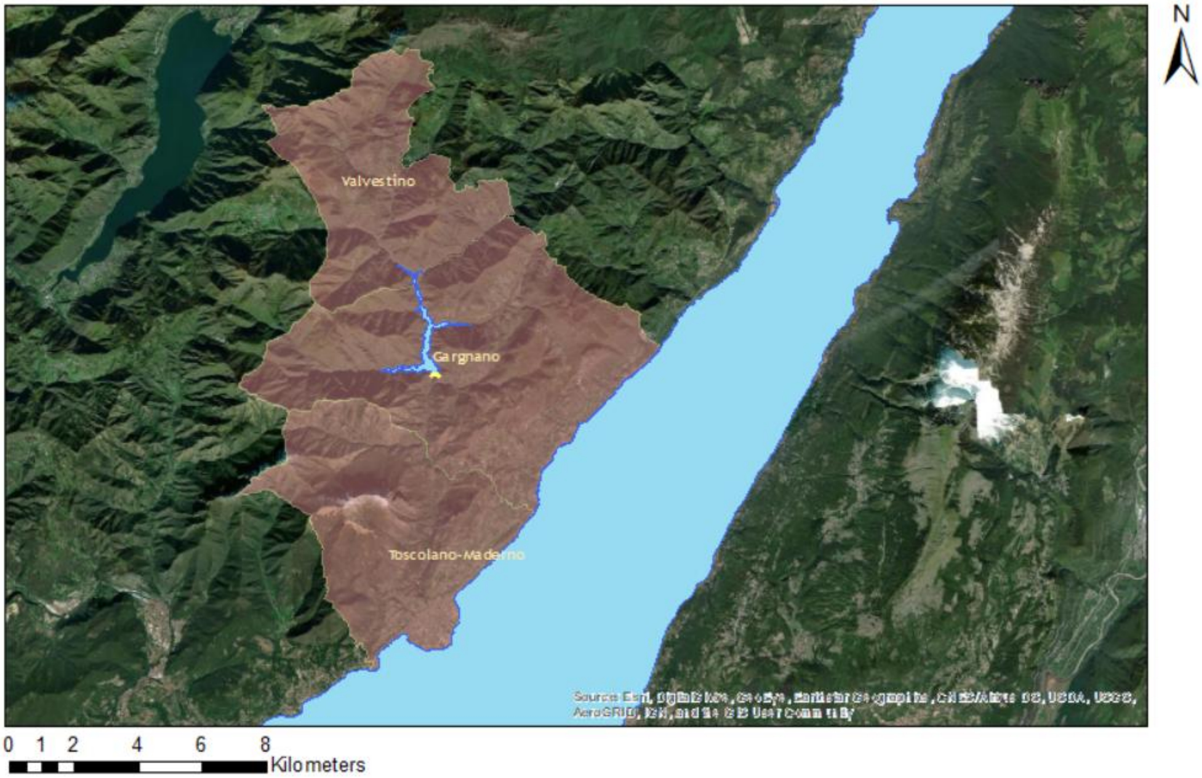

Figure 22: Geographic contextualization of the study area - focus on involved municipalities.

Another aspect related to the potentially involved municipalities taken into account by PED there is the population, which number is marked by a significant seasonal variation, due to the strong touristic attractiveness of the area. This leads to a very particular condition that is the risk itself (intended as function of hazard, vulnerability and exposure) ranging from low to very high levels within a relatively short time span. Civil Protection planning should then consider carefully the presence of a floating number of people to be evacuated and rescued, depending on the period of the year; this kind of uncertainty is usually faced through the use of Istat (*Istituto nazionale di statistica*) data, at least in a phase of preliminary organization (Regione Lombardia, 2020, pp. 18-19).

4.3 Accessibility of the area and transport system

Road network and, more in general, accessibility, is a crucial theme of emergency management. First of all, it is relevant to stress the double function of this system, that during a crisis is required to support both evacuation procedures (flows of people escaping from the impact area) and rescuers, who are instead meant to reach the critical zone and so require to employ the road system into the opposite direction. In this context, it is important to state the necessity of having at disposal a Transport Emergency Management Plan (TEMP) specifically built to increase preparedness in case of a natural disaster and, as a consequence, to establish procedures for granting rescuers an as fast as possible arrival into the involved site, as well as interventions for exposing road users to the low possible risk (Gandini et al., 2021).

In the specific case under study, an aggravating circumstance is given by the mountainous aspect of the area, related to the presence of narrow roads and hairpin bends and to the risk of interruptions caused by possible landslides. On the other hand, the fact that there are no big settlements reduces the overall demand of transport, with the consequence of a road network mainly constituted by rural connections among towns. Unfortunately, this can also be seen as a limitation, due to the complexity of managing a so ramified network. A particular situation is then the one of Toscolano Maderno, in which only two main access roads, one in Northern part and the other in Southern part are present, in addition, due to the fact that the streams cut the municipality into two sides, the lack of redundancy given by a single access can bring to very critical conditions. In the field of road accessibility, it is interesting to mention a collaboration agreement between *Regione Lombardia* and *Politecnico di Milano* Architectural and urban studies department (DAStU) that consists in a standardized in-situ analysis oriented to assess physical vulnerability of structural aggregates and to relate it to the possibility of originating rubbles in case of an event, which could determine a further obstruction to rescuers access.

Concerning other infrastructures, it can be seen that this territory is not covered by any railroad, while it is relevant to highlight the presence of several bridges. Actually, the bridges are not considered to be in particularly exposed locations, nevertheless it is important to verify and avoid as much as possible obstruction of spans, that can bring to eventual collapses and consequences both in terms of damages and loss of functionalities for road system, but also for lifelines installed on these infrastructures. Another relevant aspect is then the one related to aerial transport, extremely useful during a crisis and allowed in the considered zone by the availability of different helipads, both official ones and areas suitable to this use.

Finally, the proximity of Garda lake suggests the possibility of integrating connections also on the lakeside, through the direct accesses in Toscolano Maderno. Actually, the number of available piers and boats is varying depending on season, although a minimum service is granted for the whole year. Civil Protection can so cooperate with Navigarda (the corporation that manages transports on the lake) in order to improve procedures in case of emergency, basing on the exact knowledge of timing and quantity of people and goods associated to each boat; this particular site-related condition is deeply exploited in PED contents (Regione Lombardia, 2020, pp. 21-25).

5. Possible territorial hazards

PED reports a list of possible natural hazards, defined as "*la probabilità di accadimento di uno o più eventi potenzialmente dannosi che, con una certa intensità/magnitudo e in un determinato spazio e tempo, possono essere causa di perdite fisiche, economiche e/o sociali*", translating: "the probability of one or more potentially damaging events happening with a certain intensity in a given time and place, leading to physical, economic or social losses" (Regione Lombardia, 2020, p. 30) and based on the study of geologic, geomorphologic and hydraulics conditions of the territory. In the following, the most relevant cases will be presented, please note that in addition to these, also avalanches are addressed in official documents, even though no particular risk of this kind is evidenced in the area of interest.

5.1 Hydrogeological hazard: Floods

This topic is addressed in PED with reference to *Piano Gestione Rischio Alluvioni* (Autorità di Bacino del fiume Po, 2016), that identifies three areas depending on estimated hazard:

- Low hazard (high probability/frequency) events, characterized by return periods of 10-20 years;
- Infrequent hazard (medium probability/frequency) events, characterized by a return period of 100-200 years;
- Rare hazard (low probability/frequency) events, characterized by a return period of 500 years or more.
- Globally, the territory presents several potentially flooded areas, particularly in Toscolano Maderno municipality.

In addition to this, it should be reminded that a crucial aspect of flood hazard is the monitoring of rainfall events. Indeed, taking advantage of the meteorological observations collected in Ponte Cola/Valvestino pluviometric station (managed by Enel Green Power Italia Srl) since 1967 a singular trend can be observed. Indeed, 30 rainfall events have reached or overcome the threshold of 80 mm in 24 hours, 5 of these have even exceeded the high criticality limit corresponding to 115 mm (Ufficio Territoriale Regionale Brescia, 2016). Specifically, all the events belonging to this set have occurred in the last 25 years, proving that climate change effects are clearly affecting this environment. Obviously this is resulting in another uncertainty for emergency management, because whichever the case can be (even a routine flow discharge) it can result in a relevant event due to the unexpected contribution of rainfall and that should be carefully considered (Regione Lombardia, 2020, p. 30).

5.2 Hydrogeological hazard: Landslides

The studied area is marked by the presence of an active geological context, as it can be noticed observing the presence of karstic phenomena leading to springs along Toscolano path, and above all an important sediment transport operated by the river itself that along the centuries shaped the morphology of the area. Evidence can be found in the particular fan-shape of Toscolano Maderno that is given by the fact that the town is built on a conoid made by alluvial deposits.

For what concerns the aspect of landslides, PED relies on past experiences, with particular reference to IFFI project (*Inventario dei Fenomeni Franosi in Italia*) and to IFFI project, *Inventario dei Fenomeni Franosi in Italia* (Istituto Superiore per la Protezione e la Ricerca Ambientale, 2014), and to the document *Analisi di stabilità in condizioni statiche e pseudostatiche di alcune tipologie di frane di crollo finalizzato alla stesura di modelli di indagine e di intervento* (Regione Lombardia, CNR, 2001). All in all, the main type of landslide movement in the area is resulted to be rockfall, often triggered by heavy rainfall events, and in some cases rotational slides in loose material are reported. Particularly prone hotspots are located in Toscolano Maderno and Gargnano municipalities, unfortunately threatening both residential buildings and segments of the main road (SS45 bis), (Regione Lombardia, 2020, pp. 30-31).

5.3 Forest fire hazard

Basing on *Piano Antincendio boschivo (AIB) 2020-2022* (Regione Lombardia, 2019) the territory is split in classes depending on time occurrence, extension, severity and time-lasting events. In this case Valvestino municipality presents the worst situations, followed by Gargnano and then Toscolano Maderno. It is possible to mention that at regional scale also other datasets and classification methodologies are present, referring to stochastic models and vulnerability due to anthropization (Regione Lombardia, 2020, p. 33).

5.4 Seismic hazard

According to the latest version of *Aggiornamento delle zone sismiche in Regione Lombardia* (Regione Lombardia, 2016), each municipality belonging to Lombardia region has been classified in a seismicity scale ranging from 1 to 4, with decreasing hazard. The area of interest for the project is included in its totality into seismic zone 2, medium-high seismic probability, and it is provided with an estimation of maximum horizontal peak-ground acceleration for each municipality, as reported in Table 3.

Municipality	Province	Seismic zone	Maximum acceleration
Toscolano Maderno	BS	2	0.161385 g
Gargnano	BS	2	0.161013 g
Valvestino	BS	2	0.152365 g

Table 3: Detailed maximum horizontal peak-ground acceleration for interested municipalities, translated from PED Ponte Cola (Regione Lombardia, 2020, p. 31).

As requested by rules of Indirizzi *e Criteri per la Microzonazione Sismica* (Dipartimento della Protezione Civile, Conferenza delle Regioni e Province autonome, 2008), for each municipality a deep characterization of possible local amplification effects has been carried out, with particular interest on geological, geomorphological, geotechnical and geophysical conditions of the site. As an output a coded classification is obtained, depending on the specific proneness to site effect: Z1 for instabilities, Z2 for collapses and/or liquefaction, Z3 for topographic amplification, Z4 for lithological and geometrical amplifications, Z5 for differential behaviors. As it can be recognized from Table 4, every class is complemented by a quantitative indicator of the presence in the corresponding location.

Municipality	Province	Area	Z1 areas	Z2 areas	Z3 lines length	Z4 areas	Z5 areas
Toscolano Maderno	BS	57.60 km^2	18.14 km^2	0.59 km^2	25.00 km	12.81 km^2	-
Garganano	BS	76.47 km^2	30.33 km^2	0.35 km^2	10.45 km	12.25 km^2	-
Valvestino	BS	31.26 km^2	28.06 km^2	-	3.45 km	3.20 km^2	-

Table 4: Local seismic hazard in interested municipalities, translated from *Piano di Soccorso Rischio Sismico di Regione Lombardia* (Regione Lombardia, 2017).

Also for seismic hazard the worst conditions can be identified in Toscolano Maderno territory, with the largest part of urbanized area resulting stable, but susceptible of local amplifications. A particular condition of building stock can be recognized, quoting *Microzonazione sismica del territorio comunale – Livello1 - Comune di Toscolano Maderno (BS)*, (Zecchini, 2009) "*per quanto concerne l'amplificazione sismica dovuta a fattori litologici […] per periodi T compresi fra 0.1-0.5 s tutti i valori calcolati siano superiori ai valori soglia, diversamente, per i valori T compresi nell'intervallo 0.5-1.5 s i valori calcolati siano sempre inferiori al valore soglia. Cautela deve pertanto essere posta nei vari siti in funzione delle tipologie di strutture che ospitano o ospiteranno ai fini di evitare fenomeni di doppia risonanza terreno-struttura in caso di terremoto*" (translation: "For what is concerning seismic amplification due to lithological factors, […] for period T ranging from 0.1 s and 0.5 s all the values calculated exceed the threshold values, differently, for T belonging to the interval 0.5-1.5 s calculated values are always smaller than the threshold. Caution is then required in the different sites in function of the structural typologies that are or will be there, in order to avoid double-resonance terrain-structure phenomena in case of earthquake."). This puts the focus on the importance of knowing or at least being able to estimate the behavior of structures to external solicitations and, as mentioned previously, their capability of producing rubbles (Regione Lombardia, 2020, pp. 31-32).

6. Historical records analysis and selection of the reference seismic event

Before presenting the historical analysis of seismic event in the considered site as suggested by PED, in author's believing it is important to state why an assessment of this kind is useful in a study-case like the thesis one. For this reason, the current paragraph will be devoted to a brief introduction of historical events analysis in emergency management, while next one will focus on the characterization of Valvestino watershed area in terms of past events, following PED directions.

6.1 Past event analysis as a tool for emergency management

When addressing an area prone to some kind of natural phenomena the availability of data series or pieces of information regarding past event can become a powerful tool for avoiding catastrophic outcomes, simply by recognizing what has already happened in the past. As an example, it is possible to mention the knowledge of possible anthropic modifications to a river course or, more in general, any kind of engineering interventions. Several datasets can be constructed, if records are there, such as pluviometric series or flowrate values of a stream, but in some cases it is possible to rely even on non-scientific sources, that will probably give only qualitative information, but at least they will provide an idea of what is reasonable to expect in a certain situation. Examples of this kind can be retrieved everywhere in Italy, in commemorative monuments recording a specific water height reached during a flood in a given fluvial city (e.g. the *Padimetro* in Figure 23) or even in the toponomastic of places or roads, that often is based on what happened there (such as the case of the so called Mount Toc, who originated the dreadful landslide causing Vajont disaster in 1963, whose name, in local dialect, recall its proneness to "fall in blocks"). The most famous case is probably the description of

Vesuvio eruption (79 a.D.) witnessed and recorded by Pliny the Younger (Novum Comum, 61 - Rome, 114) that has been for a very long time the only source of information about the potential of the quiescent volcano.

Figure 23: Monumental *Padimetro*, Ferrara - record of historical flood levels (Careddu, 2018).

Nowadays the situation is clearly very different, especially in a country like Italy that is so exposed to different kinds of hazard and, consequently deeply studied. Anyway, even in this context often crucial information can be collected in historical records, because they can be the only source for events that have a so long return period that could not be recorded by any modern instrument. This statement stands true also for earthquake catalogues, that are at the base of seismic zonation. In this field, that is actually the one of interest for the project, a very useful platform is INGV (*Istituto Nazionale di Geofisica e Vulcanologia*) one, from which data and, when available, graphs and geospatial information can be recovered through a website.

6.2 Reference event for the considered study-case

The seismic event that will be used as a reference for the whole project (and has been used for PED development as well) happened on November 24th 2004, at 22:59 GMT (23:59, local).

Figure 24reports a simplified representation of the seismic scenario, in terms of peak ground acceleration (PGA) distribution, which has been obtained basing on the available epicentral data and taking advantage of a modified version of Sabetta-Pugliese ground motion prediction equation (Bindi et al., 2009).

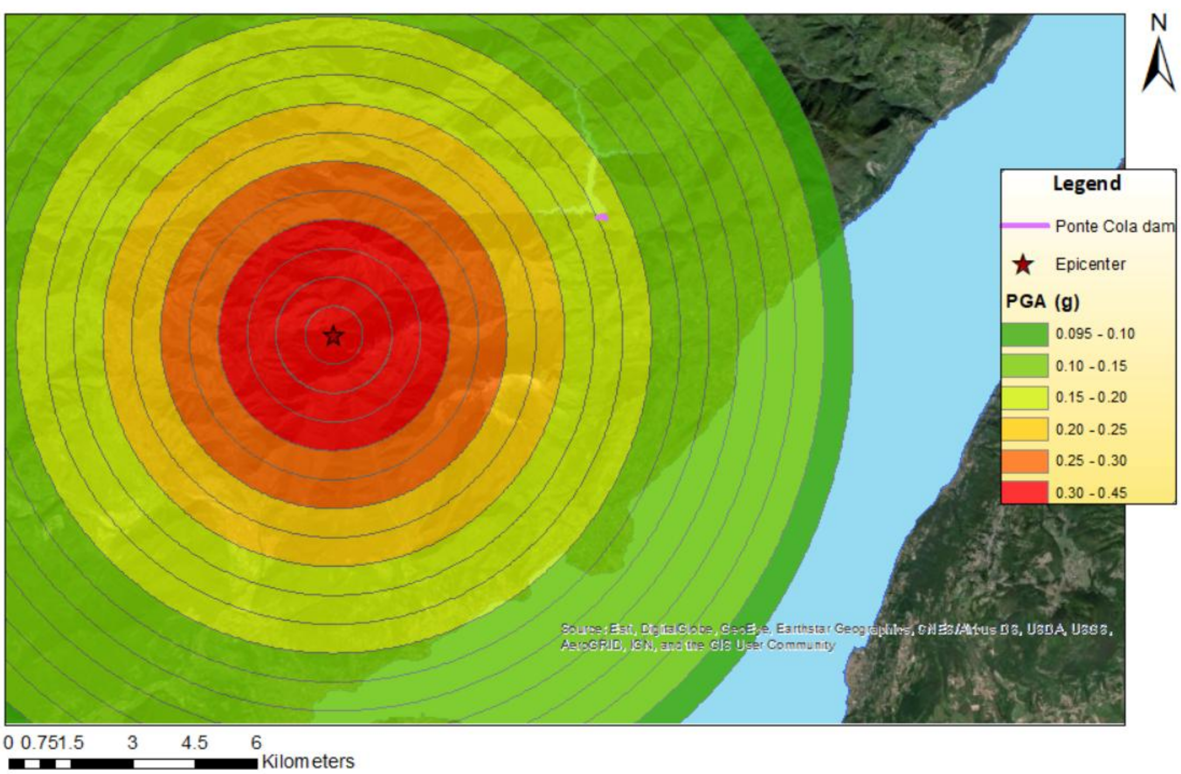

Figure 24: Simplified seismic scenario for 11/24/2004 event.

In Table 5 the list of local historical event reported by *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) is shown.

Date	Time	Epicentral area	Epicentral intensity	Magnitude
05/01/1892	-	Western Garda	6-7	4.96
09/08/1892	07:58	Valle d'Alpone	6-7	4.91
27/11/1894	05:07	Bresciano	6	4.89
16/11/1898	-	Western Garda	6	4.63
30/10/1901	14:49	Western Garda	7-8	5.44
24/12/1909	18:40	Western Garda	5	4.17
27/10/1914	09:22	Lucchesia	7	5.63
19/02/1932	12:57	Eastern Garda	7-8	5.16
23/11/1961	01:12	Bergamo Prealps	6-7	4.86
19/04/1970	18:16	Western Garda	5	4.55
09/11/1983	16:29	Parmense	6-7	5.04
13/09/1989	21:54	Vicenza Prealps	6-7	4.85
13/11/2002	10:48	Franciacorta	5	4.21
24/11/2004	**22:59**	**Western Garda**	**7-8**	**5.20**

Table 5: Seismic events interesting Toscolano Maderno between 1892 and 2004, translated from *Database Macrosismico Italiano (DBMI15)*, (Istituto Nazionale di Geofisica e Vulcanologia, 2015).

As it can be read in tables, an earthquake with a local magnitude of 5.2 (quite a large event, considering the seismicity of the context) hit the western side of Garda lake, with hypocenter localized at a depth ranging from 6 km and 8 km, at a distance of 7 km from Ponte Cola dam. A seismic swarm followed the event (as it can be noticed in Table 6), while for a previous similar event it should be needed to go back in time to 1901 (local magnitude of 5.5).

Date	Time	Local magnitude
24/11/2004	**22:59**	**5.2**
24/11/2004	23:48	2.1
24/11/2004	23:53	2.1
24/11/2004	23:55	2.1
25/11/2004	15:38	2.2
25/11/2004	21:28	2.2
26/11/2004	05:39	2.7
27/11/2004	08:44	2.7
27/11/2004	20:49	2.7
27/11/2004	21:19	2.4
28/11/2004	12:26	2.3
12/12/2004	17:09	1.6
31/12/2004	02:13	1.8

Table 6: Garda area seismic swarm in November-December 2004, translated from *Quaderni di Geofisica n.88* (Istituto Nazionale di Geofisica e Vulcanologia, 2011).

It is possible to mention that in MCS scale (based on qualitative reconnaissance of damage) a macroseismic intensity of VII – VIII degree was assigned, with collapses concentrated in the historical centers and not affecting accessibility systems. Horizontal acceleration, that is one of the most important parameters in terms of dams seismic emergency management, as it will be presented in paragraph 8.5, reached a value of 0.13g (Ruggeri, 2008). The responsible engineer reported then, after specific inspections, that no damages were present in dam body nor in embankment, that hydraulic system was not affected and that no danger to population appeared to be there (ENEL, 2004). Also instrumental checks and diagrams records were performed, as indicated by the ruling directive that, it is of interest to be pointed out, was updated some years later and so it will not be the same as the one indicated in project development.

7. Civil Protection involvement in operational aspects of PED

7.1 Italian Civil Protection organization and planning guidelines

Before going on with the description of the actual involvement of Civil protection as a stakeholder of crisis management procedures depicted in PED, in this paragraph is necessary to have a brief introduction about the organization and the general workflow that lays behind the action of Italian Civil Protection, whose work is universally recognized as one of the best of the entire globe among equivalent organizations.

Civil Protection activities are mainly led by three goals: permanent monitoring and control of possible accidents occurring in Italian territory, identification of particular risks for population or assets, guaranteeing a coordinated and effective intervention where needed. All of these actions are the focus of the main core of the body, National Situation Room (*Sala Italia*), that represents the highest level of the organization, directly depending from President of Council of Ministries. Indeed, one of the fundamental principles of action is subsidiarity, that specifically addresses at different levels institutions with coherent roles and objectives in emergency management. Actually, in Italy, the responsibility for implementing civil protection measures falls with the lowest possible administrative level, designing so the mayor as authority in chief and responsible of the action. This doesn't mean that other institutional figures are not involved in the process, but they're activated only in case of needs that exceed local resources availability, through a fixed hierarchical organization, coordinated, as mentioned before, by the Prime Minister (Marchionni & Gandini, 2021).

Figure 25 shows the main control centers that can be activated depending on the entity of the crisis, ranging from the municipal level with C.O.C., to the national DI.COMA.C. The latter can be identified as the focal point in case of a disaster, by which all information and decision must transit; for this reason, the peculiar feature of DI.COMA.C. is the fact that it has not an established location, but in each occasion a specific place has to be decided, in a strategic position, as close as possible to the site, in order to have efficient information exchange, but still in an area sufficiently distant with respect to the possible direct involvement in evolutions of the event. As an example, it can be mentioned that during Amatrice seismic swarm in 2016 DI.COMA.C. was located in Rieti municipality, even though the site of the event was in the same region as Rome (where the national control center is situated).

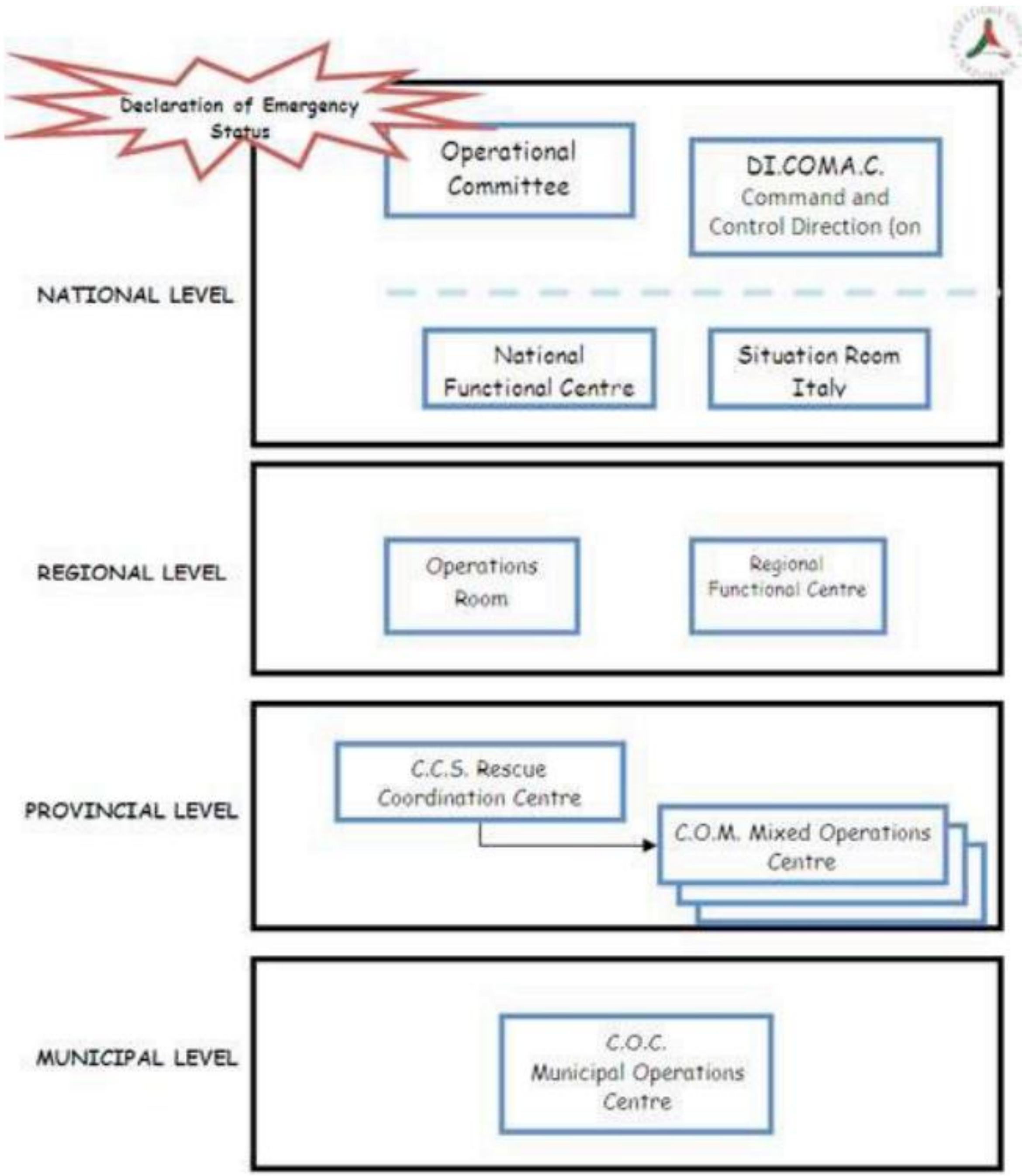

Figure 25: Italian Civil Protection operational organization (Floristella, 2014).

Another important aspect to be mentioned is the one of planning action, based on *Augustus* method guidelines (Galanti, 2008), for which clear and simplified outlines must be established, so that same schemes can reasonably be followed in all the hierarchical level of Civil Protection organization already presented. The concept that lays behind this approach is expressed by Roman emperor Augustus (Rome, 63 b.C. – Nola, 14 a.D.), after who the method was named that states, in translation, "the value of planning is reduced in proportion to the complexity of the state of things", summarizing the key elements of simplicity and flexibility needed to grant plan applicability. The method provides for the involvement of the most adequate control center, which will be capable of activating up to fourteen "support functions", represented by collaborative bodies and technical experts in as many fields that can collaborate to the solution of the crisis, listed in Table 7. All the institutions, local or national, will be characterized by the possibility of using this same concept while planning civil protection measures, so that it results in an easier and common approach. Lastly, *Augustus* method characteristics consent a particularly efficient spreading of plans, both among institutions and operators, a crucial aspect considering the necessity of exercising whichever plan, otherwise there would be the risk to have personal not able to apply the requested measure and, in consequence, a useless (although maybe very detailed) emergency plan (Marchionni & Gandini, 2021).

Main operational structures in *Sala Italia*			
F.1	Technical and planning function	**F.8**	Primary services
F.2	Health	**F.9**	Damage survey of people and goods
F.3	Mass-media and information function	**F.10**	Operational structures
F.4	Voluntary service function	**F.11**	Local authorities
F.5	Means and materials	**F.12**	Dangerous materials
F.6	Transports, road conditions and traffic	**F.13**	Assistance to the population
F.7	Telecommunications	**F.14**	Coordination operative centers

Table 7: Support functions available in Civil Protection emergency management (Marchionni & Gandini, 2021).

7.2 PED operational prescriptions: Alert phases

Making a step further, it is possible to remind that the second part of PED is strictly related to operational aspects of Civil Protection interventions, in case of hazard threatening the territory and its population, caused by the dam. As already mentioned, the Plan provides two different cases with specific conditions of activation and rule of intervention, respectively *Rischio diga* (literally, Dam risk) and *Rischio idraulico a valle* (literally, Hydraulic downstream risk). Clearly, the entities of the possible outcomes are very different in the two cases, with a less impactful situation in second case and, realistically, an occurrence that can eventually evolve up to dramatic results, such in the case of the collapse of the dam. Coherently with this distinction, the way of approaching them is totally different, starting from the statement of only two level of alert in the lighter case (Pre-Alert, Alert) against a more complex system organized in 4 level (Pre-Alert, Enforced Surveillance, Danger, Collapse) in the other one. In general terms, it can be stated that for *Rischio idraulico a valle* the main object to be monitored (and capable of determining the activation of a higher level of alert) is the value of discharged flowrate, while in *Rischio Diga* the situation becomes more complex and it is leaded by three parameters: reservoir level, anomalies in dam-related facilities and possible occurrence of a seism.

The standard workflow, at least for what concerns Lombardia region, regarding alert phases can be described as follows. Dam manager activates an operational phase (among the previously mentioned ones), then *Regione Lombardia* will inform downstream municipalities and involved entities and activates Flood service; lastly, each institution will apply the correct intervention model, as described in its own planning phase.

There should be a particular attention to some aspects:

- Identification of area interested by scenarios;
- Recognition of strategical and relevant buildings (Regione Lombardia, 2019);
- Determination of *Aree di ammassamento soccorritori* (rescuers clumping areas).

With particular reference to the definition of important areas for emergency management, different cases can be mentioned, such as clumping areas (responsibility of regional institutions), Waiting and Recover areas (managed by municipalities). In order to select the best location, the main aspects that should be taken into account are the number of people that will be recovered (relocated, people who lost their houses and so), dimension of the investigated area and its accessibility (crucial for several reason, among which the need of bring goods to involved population); lastly, as mentioned before in DI.COMA.C. case, the final location must mandatorily be placed in a zone that is considered to be as safe as possible with respect to the ongoing event, also considering the possibility of further ones, as in the case of seismic swarms (Belloni, 2018).

7.2.1 A practical issue: Dam accessibility in inspection procedures

As introduced, one of the essential steps of dam crisis workflow is the activation of procedures for the dam body inspections, specifically requested by regulations in order to establish the most suitable level of alert. In section 8.5 a tool for supporting this operations will be presented, while for the moment it is possible to make some consideration on the practical deployment of the procedure, with particular reference to the issue of dam accessibility.

To be aware of the dam conditions as a whole, it is indeed worth taking advantage of aerial vehicles and in particular of UAV (Unmanned Aerial Vehicle, also known as drones) and helicopters. These two types of aircrafts are suitable for different intentions.

Indeed, UAVs are able to detect small details, so e.g., small cracks in the dam's structure, even in inaccessible areas, but some disadvantages should be considered, such as the fact that the weather influences in a fundamental way the inspection; extreme temperatures require then a particular carefulness and even presence of fog affects the results quality. Drones employment can be suggested when it is important to provide an adequate dam's photo coverage, in order to be able to create a high resolution point cloud. Moreover, in this situation more than one inspection is suggested, so batteries charges and backup batteries are always needed, in addition to memory cards. This solution allows also a safe investigation of the dam if the road network that leads to the structure is interrupted or if an evident life-threatening situation is supposed to exist.

Helicopters are instead crucial to obtain a general overview of the dam's surroundings, as not just the dam's face has to be checked, but also associated structures and infrastructures. It is first fundamental to check spillways, as if they are damaged an eventual emergency discharge of the dam may not be possible. Then, another important check concerns the penstock pipes, so excluding damages to these infrastructures is essential to guarantee the normal functioning of the hydropower plants that are located downstream.

Concerning UAV and helicopters, a special regard to the national regulations is needed: in Italy a no-fly zone for drones has been set up within a radius of 8 km in the surroundings of airports.

The legislation establishes the same rules both for airports and for heliports, so in case that the dam is located within the specified distance from a heliport, a derogation to the national law is required. In this regards, useful pieces of information come directly from PED (Regione Lombardia, 2020), in which, as mentioned in paragraph 4.3, the infrastructural conditions of the area are reported, including areas suitable as helipads.

7.3 PED operational prescriptions: Collapse scenario and related workflow

As mentioned previously, PED addresses two main scenarios and correlated operational workflows; in the current project an elicitation was necessary, in order to select which of them would be taken into account in order to provide an applicative example in the developed emergency-support platform. After having considered the possible implications emerging from the two different opportunities, the collapse scenario (*Rischio diga*) was selected.

This choice can be motivated in different ways, stating that a larger impact would obviously result in more evident outcomes in the area, but also considering the fact that the so-called “worst case” will be capable of highlighting the potentiality of this project application, due to the multifaceted conditions that can be generated in site by this kind of events.

7.3.1 Ponte Cola *Rischio diga* scenario

In order to seize the situation, it is possible to consider the results of a study performed by ISMES S.p.A. in 1990, regarding some hydraulic simulations in case of dam break of Ponte Cola dam. More in detail, downstream riverbed of Toscolano torrent was cut in a series of fluvial sections (Fig. 26) and a monodimensional model was applied in order to estimate the behavior of the possible floodwave in terms of different parameters; as it can be seen in Table 8 in less than six minutes a wave of 8 m will enter in Garda lake (section 10, while section 9 corresponds to Toscolano Maderno center).

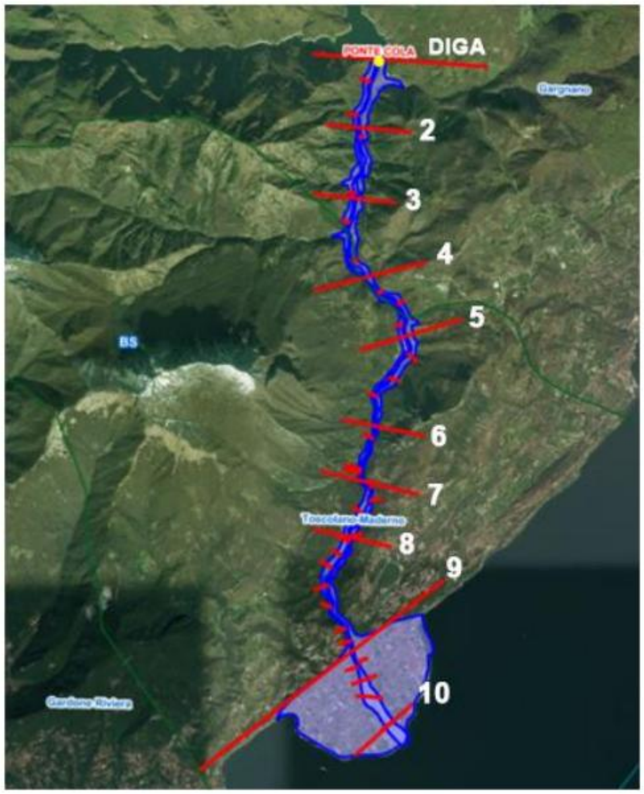

Figure 26: Fluvial sections considered in collapse hydraulic simulation, from *Ministero delle Infrastrutture e dei Trasporti* WebGIS application (Regione Lombardia, 2020, p. 45).

As a critical interpretation some topics should be pointed out; first of all, ISMES project is quite old and performed with poorly detailed processes and then it is useful to remember that it took into account maximum levels in reservoir and do not consider the safety limitations imposed in 2003, mentioned in dam characterization paragraph. The discrepancy between the actual maximum level and the allowed one for safety leads to the consideration that all simulations and previsions that can be made approaching the water body from a purely geometric point of view (considering so the actual reservoir capacity), without taking into account the legal constraints, may result in an overestimation of the real possible events. All in all, the mentioned project outcomes are clearly representing an overstatement, but still they can be reliable in order to identify the entity of a similar event, at least from a territorial point of view.

Furthermore, these results were officially used as a base to identify points on the territory that has been deemed crucial for emergency management deployment (Regione Lombardia, 2020).

Section n.	Progressive distance	Flowrate	Water height	Levels	Velocity	Time
Dam	0 m	174625 m^3/s	62.60 m	480.60 m	21.43 m/s	0 s
2	912 m	146532 m^3/s	49.79 m	424.74 m	50.03 m/s	18.20 s
3	1898 m	134241 m^3/s	61.66 m	411.67 m	42.35 m/s	40.00 s
4	3001 m	125241 m^3/s	48.97 m	373.96 m	39.35 m/s	69.18 s
5	3968 m	121462 m^3/s	35.69 m	335.64 m	39.08 m/s	93.98 s
6	5301 m	118338 m^3/s	42.73 m	292.50 m	33.43 m/s	130.29 s
7	6119 m	118160 m^3/s	26.57 m	176.62 m	42.53 m/s	154.15 s
8	6924 m	118079 m^3/s	36.98 m	161.98 m	38.61 m/s	174.07 s
9	**8533 m**	**117059 m^3/s**	**13.43 m**	**103.44 m**	**15.12 m/s**	**240.00 s**
10	**9600 m**	**107455 m^3/s**	**8.09 m**	**76.35 m**	**7.70 m/s**	**345.63 s**

Table 8: Results of dam break hydraulic simulation, translated from *Studio ISMES* (ISMES S.p.A., 1990).

7.3.2 Operational workflow and involved stakeholders

In the light of the foregoing, here the operational procedure related to *Rischio diga* scenario will be presented, as described in PED (whose consultation is anyway suggested for retrieving a more detailed description of emergency workflow). So, it is possible to list the main involved bodies with the corresponding role in general terms, while for a more detailed description of the actions that are planned to be undertaken for each alert phase, the reader can refer to the PED official document.

- Dam manager: supervises reservoir and dam system conditions, activates (and deactivates after the emergency) different alert levels and it is responsible for inspections;
- *Regione Lombardia* – Civil Protection: grant information, coordinate actions and provide support to local administrations and populations, activate regional crisis unit;

- *Ufficio Territoriale Regionale* Brescia (Territorial regional office): performs *Quaderno di Presidio di Bacino* actions, directly involving citizens and competent bodies along the riverside;
- Brescia Prefecture: activates the CCS, involves fire brigades and manages information about clumping areas;
- Brescia Province: collects provincial resources to support municipalities, evaluates traffic and infrastructural conditions, eventually activating measures according to TMP (Traffic Management Plan), acts to enforce optimization between lower and higher hierarchical levels;
- Municipalities (Toscolano Maderno, Gargnano, Valvestino): activate municipal civil protection plans, coordinate with other bodies, share information from the emergency site, provide in an efficient way direct support to population;
- *Ufficio Gestione Navigazione lago di Garda* (Garda lake navigation management office): manages public line services and coherently informs users (Regione Lombardia, 2020).

From Figure 27 to Figure 30 a summary of the above presented stakeholders roles and correlations within the four seismic emergency alert phases is outlined. The schemes are directly based on PED operational guidelines (Regione Lombardia, 2020), considering an as detailed as possible point of view. In order to achieve a more efficient comprehension of these graphical representations, a codification through icons was inserted: SOS icon corresponds to alarm communications, emergency symbol to the deployment of specific actions during the crisis, mail one is related to an exchange of information among stakeholders and the person icon is referred to bodies involved in the current phase, not only as information receivers, but also as active participants.

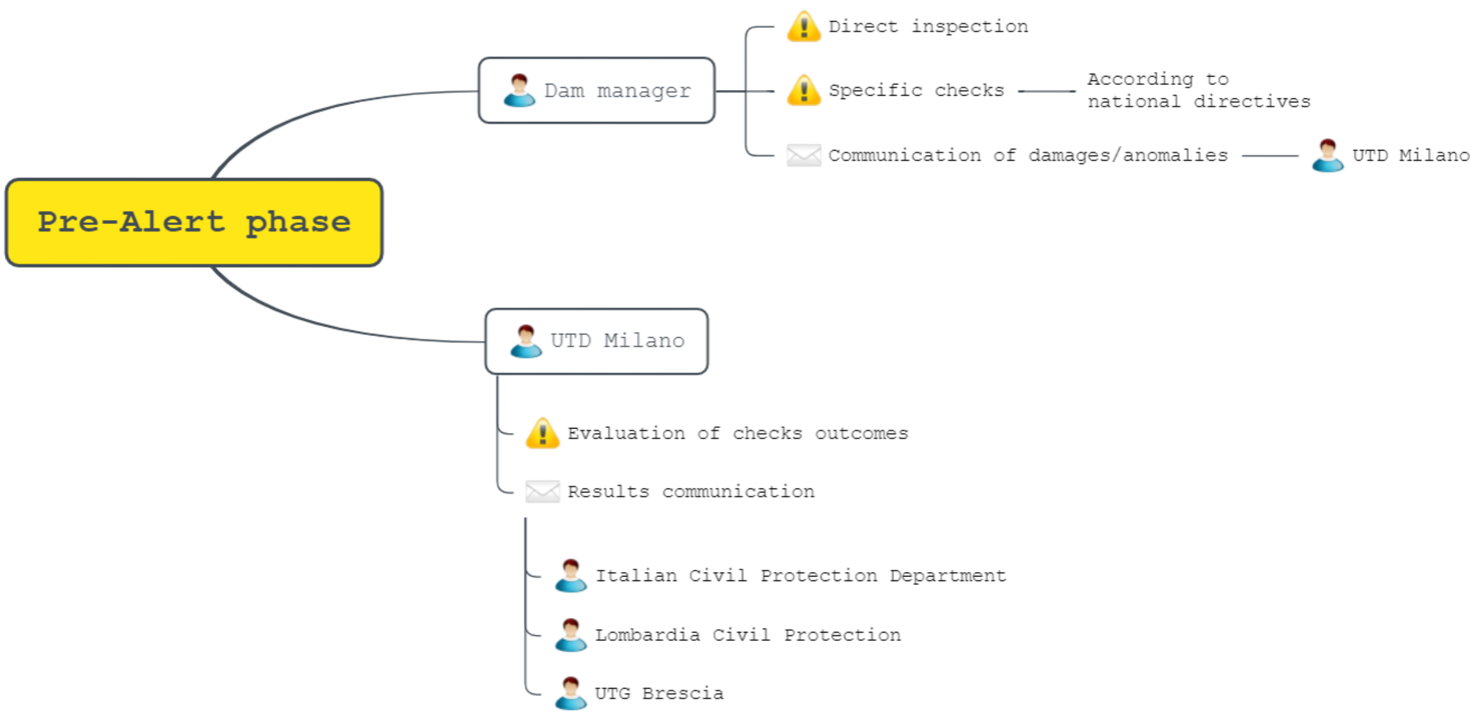

Figure 27: PED-prescribed workflow in Pre-Alert phase (drawn by the author).

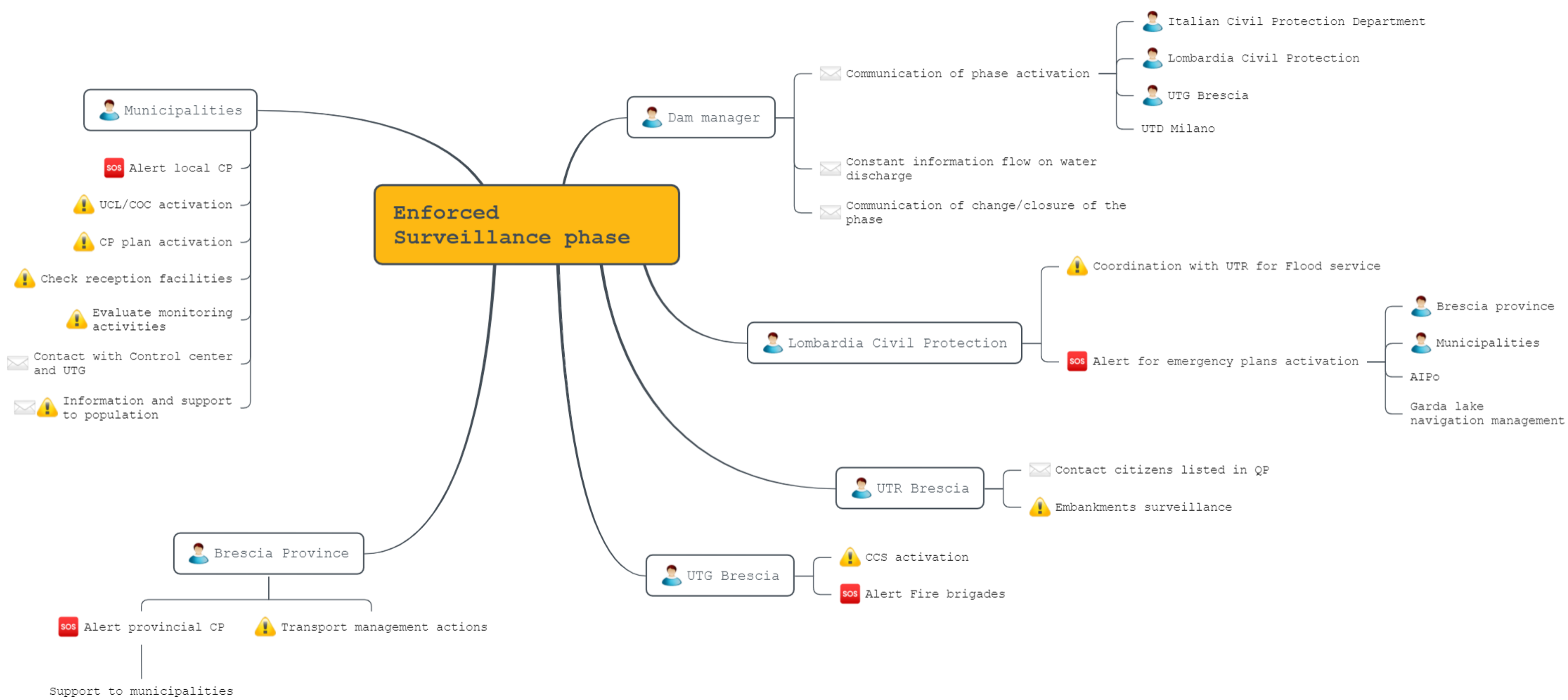

Figure 28: PED-prescribed workflow in Enforced Surveillance phase (drawn by the author).

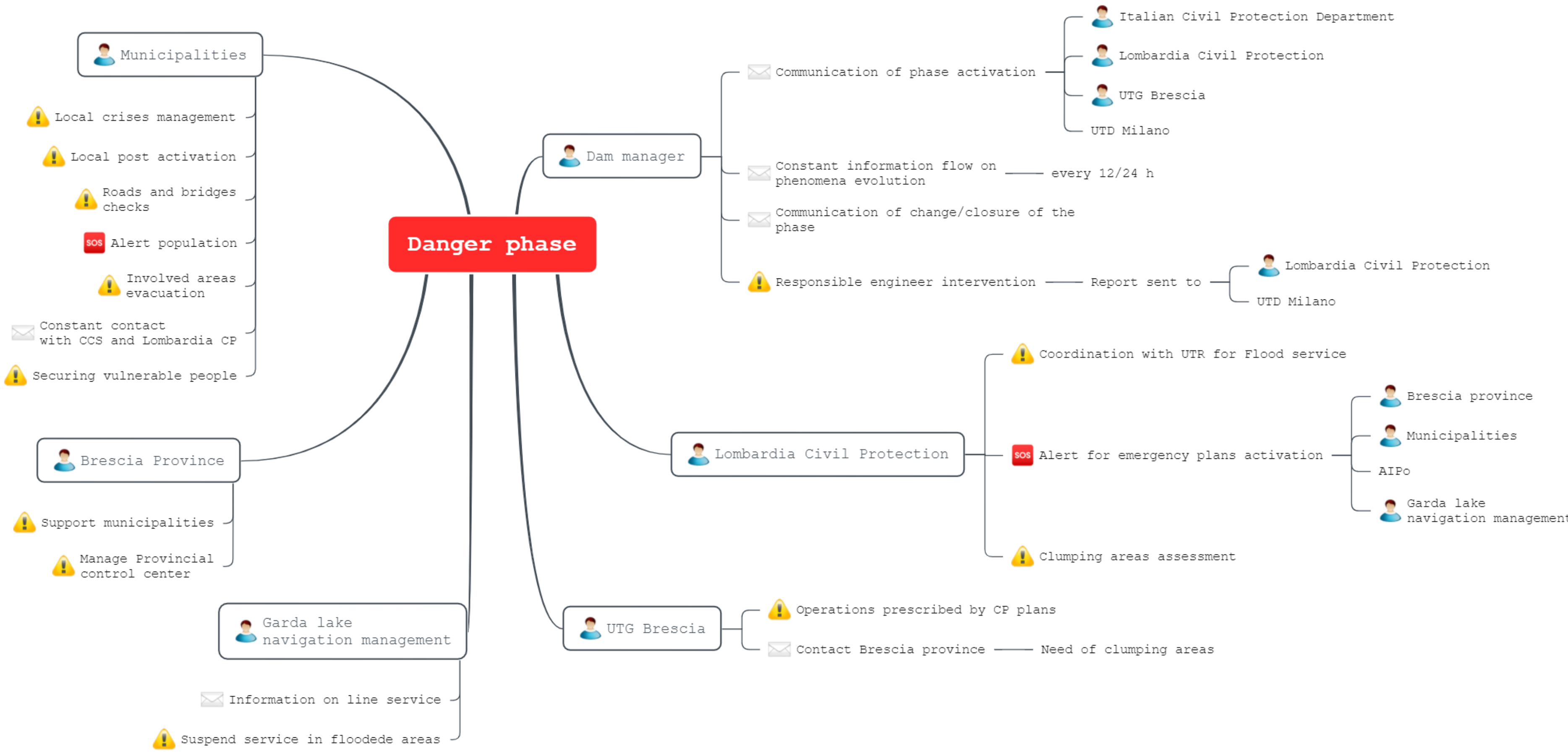

Figure 29: PED-prescribed workflow in Danger phase (drawn by the author).

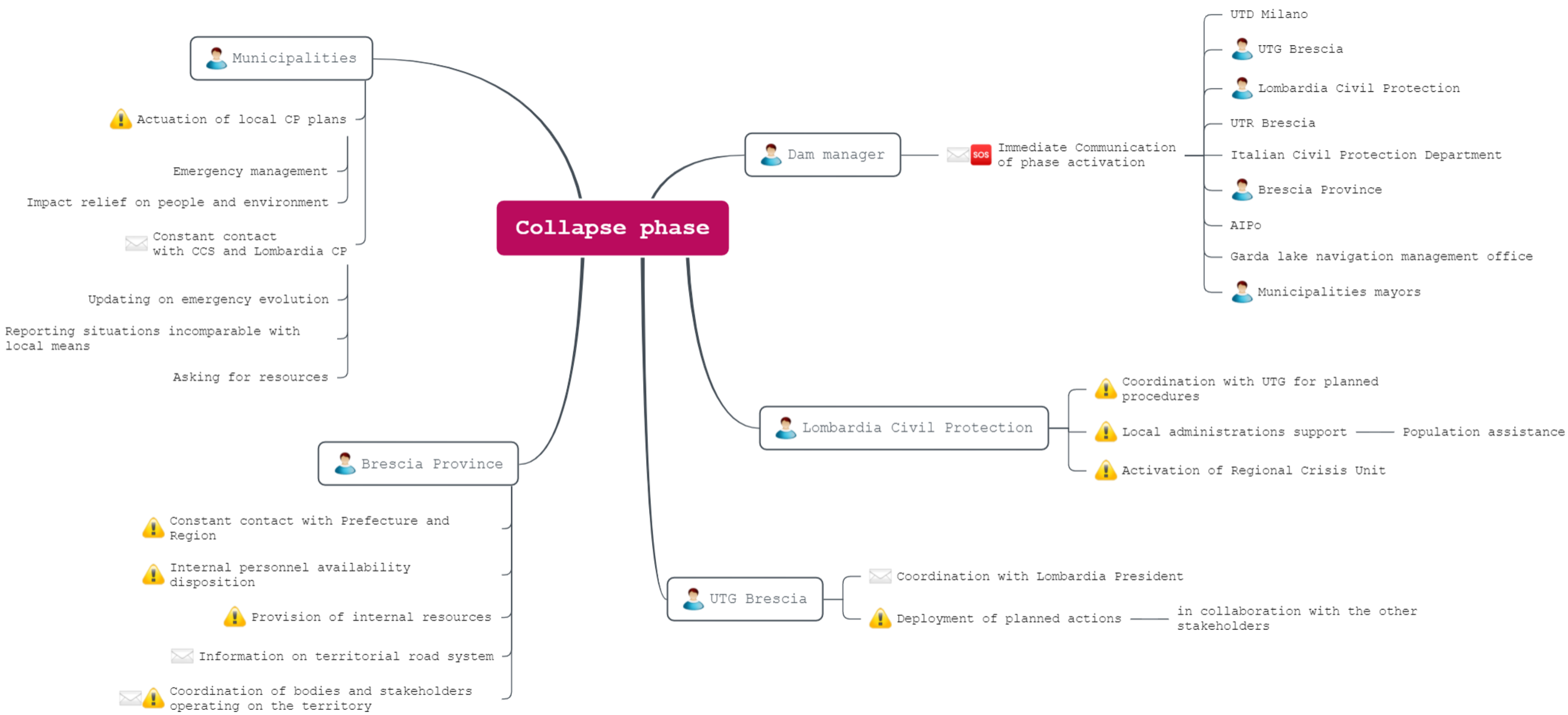

Figure 30: PED-prescribed workflow in Collapse phase (drawn by the author).

8. Project platform to support Civil Protection procedures

8.1 Introduction to the designed WebGIS platform

The design phase of the current thesis project is based, as previously mentioned, on the development of a prototype of WebGIS service, with the specific goal of providing a tool to enforce Civil Protection operations. Subsequently, a series of possible future developments were analyzed, as presented at the end of this chapter.

In detail, the main concept that lies behind the whole elaboration is to provide an advanced tool for the deployment of crisis management processes, with different levels of usability. The platform will then result in a system combining different field of interests related to emergency management, ranging from the decisional aspect to the educational one (aiming to involve also population, as it will be shown in next paragraphs), obviously with particular regard to the operational phase, whose deployment is responsibility of territorial control center operators. This project is indeed principally devoted to the fulfillment of goals of the last mentioned category of users, with the expectation of providing them with a tool for integrating, visualizing and exploring different datasets that can be useful in order to decide how the operational phase of emergency management should be carried out. In addition, a critical observation of the material made available on the platform could also supply the users with support to understand how the whole process could be improved. In terms of content, it is possible to mention the fact that obviously a relevant part of the datasets is composed by geospatial data, but also several kinds of documents, among which papers and schemes, are embedded in the project, in order to provide an as wide as possible coverage of information.

In the following paragraphs, the integration of the platform in the context of PED application during seismic emergency will be presented, but it is relevant to state that this should be observed only as an example devoted to demonstrate the capabilities of the system contextualized in a real case. Indeed, one of this project’s strong points is the high level of customizability that would consent to re-shape the platform in order to satisfy the needs of

Civil Protection in whichever kind of emergency management case and, furthermore, also its possible deployment in peacetime should be carefully analyzed.

8.2 Designed platform structure and available functionalities

The project was developed in GeoNode environment, taking advantage of the tools that are provided by this system, which is suitable for the development of a platform, even for users who are not expert in coding languages.

In the following, a general overview of available functionalities complemented with screenshots coming from the implemented prototype is provided.

Figure 31 shows the first page that the user will reach once the website is loaded. Then, in order to be free of explore the platform in its different aspects, the login is required.

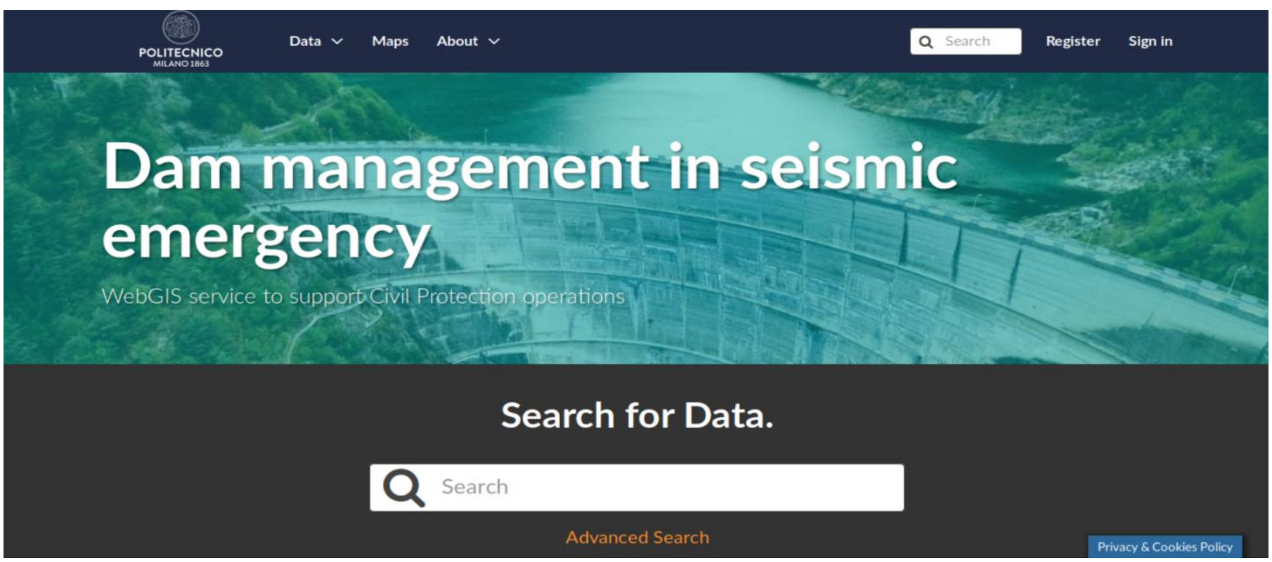

Figure 31: Implemented GeoNode platform, main page.

As far as user topic is addressed, it is even possible to open from a dedicated menu the page related to the different profiles authorized to use the platform. It should be noticed that creating new users is a privilege of the administrator (represented by the author, in Figure 32), as well as the possibility of grouping people depending e.g. on the organization they belong to and, most important, the power of establishing specific roles for the users. Specifically, the admin will be able to define for each uploaded dataset, which categories of users can access it and for each category which rights it has with respect to data (only visualization, download, possibility of combining layers and so on); furthermore, it can be pointed out that it is also possible to have a shared profile, accessible through same credentials, useful in case of a collaborative deployment of the system (e.g. a control room can be provided by a single profile instead of having one for each of the operators working in it). Users profiles can then be completed and detailed (on the base of their permissions) including additional content such as an avatar. As a matter of example, Figure 32 shows the scheme of the proposed users, in which apart from the administrator, available profiles can be recognized in Civil Protection control center, External expert, GIS technician, Decision maker and Citizen.

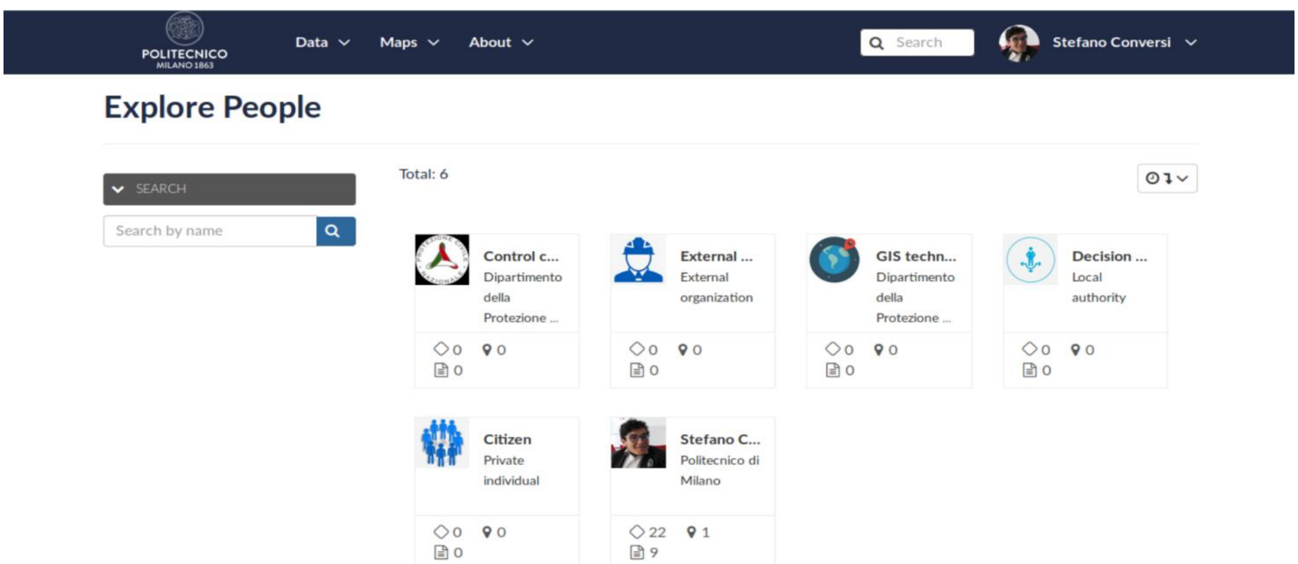

Figure 32: Implemented GeoNode platform, users list.

Moving a step towards data inspection, three main different ways of accessing dataset are provided. First of all, as shown in the first picture, a search bar is available inside the user interface immediately after the login.

Then, at the bottom of the page (Fig. 33), an overview of the platform content is visible, in terms of layers, maps, documents and users and by clicking on the correspondent icon, the different pages will be loaded.

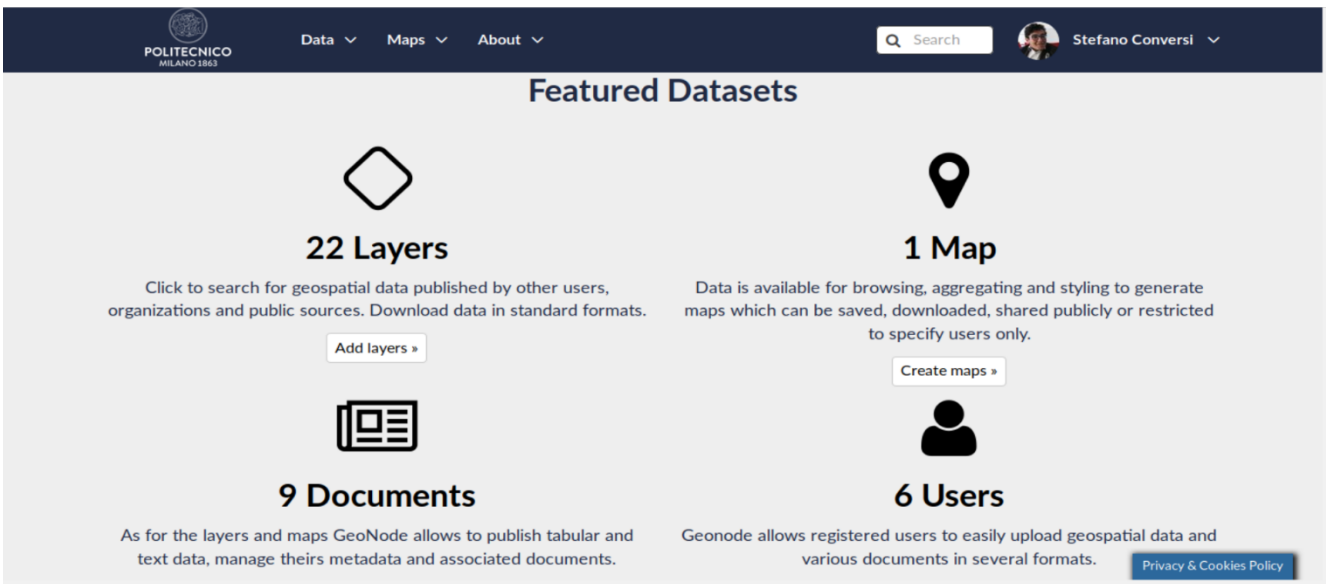

Figure 33: Implemented GeoNode platform, featured datasets.

The third method of accessing the dataset (available only for layer ones) is the most user friendly, implemented with the aim of increasing data accessibility, simplifying in this way the archive exploitation. In particular, as Figure 34 shows, all the data uploaded in the system can be categorized into one of the twenty presented macro-areas of interest. Inserting this simple information during the uploading, will let the platform store the data and documents into the correct category, so that they can easily be reached by the users simply by selecting the symbol associated to the fields of interest. As an example, it can be reported the presence of the reference seism set of layers into the category “Geoscience”.

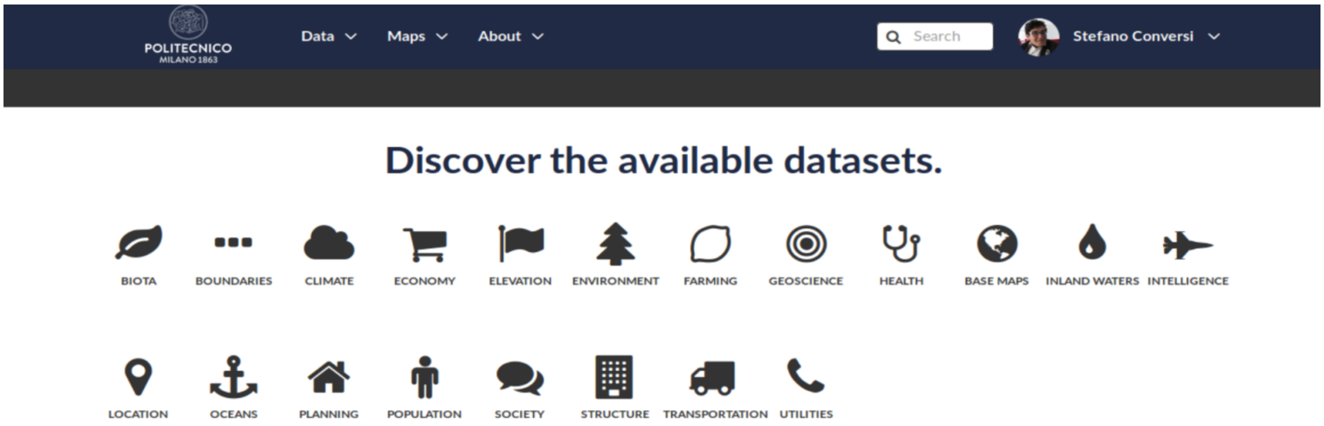

Figure 34: Implemented GeoNode platform, datasets categories.

Continuing with the description of different pages, it is possible to address the ones related to the exploration of Documents datasets. In particular it is relevant to underline that several file formats belong to this category, such as Word documents, Excel sheets, presentations, images and more in general files that cannot be georeferenced and so are not contained in layer category. Furthermore, this sort of archive-service was enhanced by the upload of a specific guidelines document aimed to provide users with information both on the usability of the system itself and, most relevant, on the interconnections among datasets, so that even non-expert users of the platform would be helped in understanding which data and documents will be profitable for their own interest, e.g. in this text it is specified what to look at in the different emergencies phases, such as the survey procedure for first inspection or the cascade event scheme for having a general idea of what can happen in the area (Conversi et al., 2021).

In order to enhance the usability of the service, then, each of the documents was complemented with a short abstract and linked (through the dedicated function) to its reference layers, allowing a further improvement of the accessibility for users; in this way layers can be accessed through documents pages and vice versa, as shown in Figure 35 in the example of the official emergency contact scheme drawn by Civil Protection for the area of interest (Prefettura di Brescia, 2019).

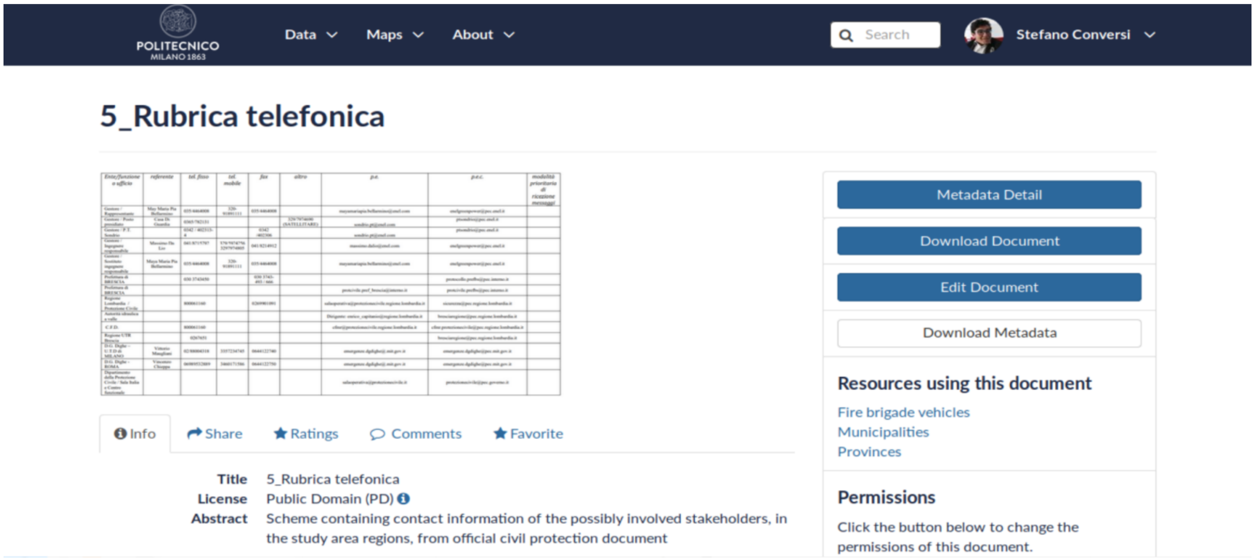

Figure 35: Implemented GeoNode platform, example of document.

As far as geodata are regarded, it is important to state that for each file some additional information was uploaded, in order to better specify what the data are representing and how the operators may take advantage of them. In detail, geodata were complemented by metadata, including an abstract, the source, license and quality details (Conversi et al., 2021). Knowing this, it is possible to analyze more in depth the available tools for layer analyses and map production.

First of all, once a layer is selected, the opened window will show an interactive preview version of the data set, overlayed to an OpenStreetMap (OSM) basemap (Fig. 36). Near to this map a series of commands for its use is listed: enlarge layer view, download layer, view metadata, download metadata and create a map starting from the layer (this function will be discussed in the following) or even adding the layer itself to an already existing one. Still addressing visualization layout, the legend is visible in this part of the page, as well as the layer style selection among available ones.

Some pieces of information will be shown immediately below, such as the abstract, license characteristic, data author and category (basically, what is contained in metadata). In addition, a tool for layer attribute exploration is present, together with other functions related to a collaborative use of the platform, such as sharing one or the ones devoted to rate and comment the specific data.

Lastly, it is possible to notice the presence of two sets of information on other material correlated to the considered data, such as maps using the layer and documents associated to it, in terms of field of interests (complementing what has been exposed in documents discussion).

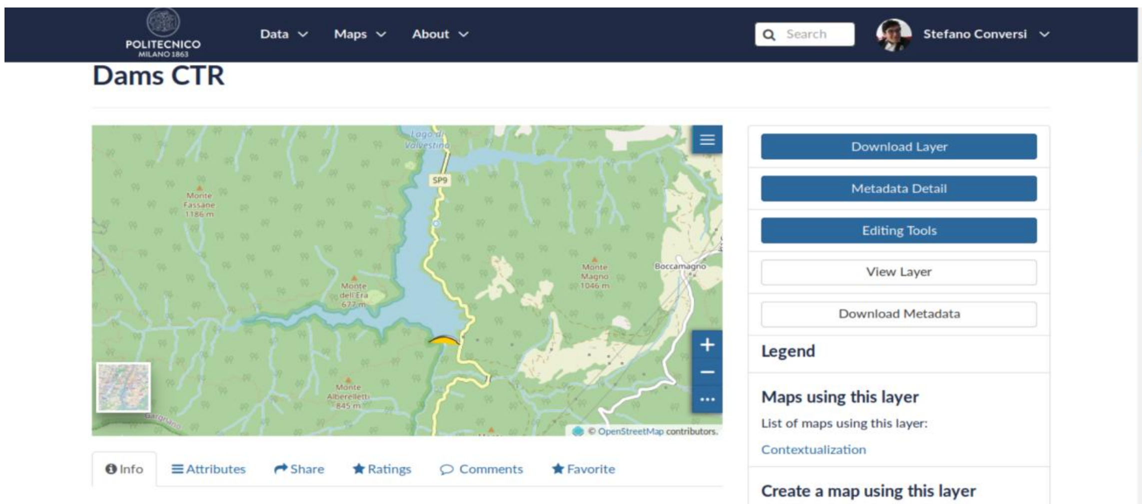

Figure 36: Implemented GeoNode platform, example of layer.

By clicking on the command "Create a map" another interface will be displayed, as shown in Figure 37. First of all, in the bottom part of the frame information on scale and coordinates are located. In the right menu several visualization tools can be found, starting from zoom functionalities (also zoom-out to maximum extent), full screen display and menu collapsing in order not to interfere with map analysis.

Furthermore, from the mentioned menu it is possible to activate or deactivate the possibility of querying objects belonging to the plotted layers by clicking on them (with the result of displaying each selected shape attribute table). Actually, another functionality for punctual analysis can be retrieved in the search bar present in the upper part, through which is possible to insert information on a specific location on the map (e.g. name or address), so to trigger the research on Open Street Map (OSM) database and obtain as an output a tag in the selected point.

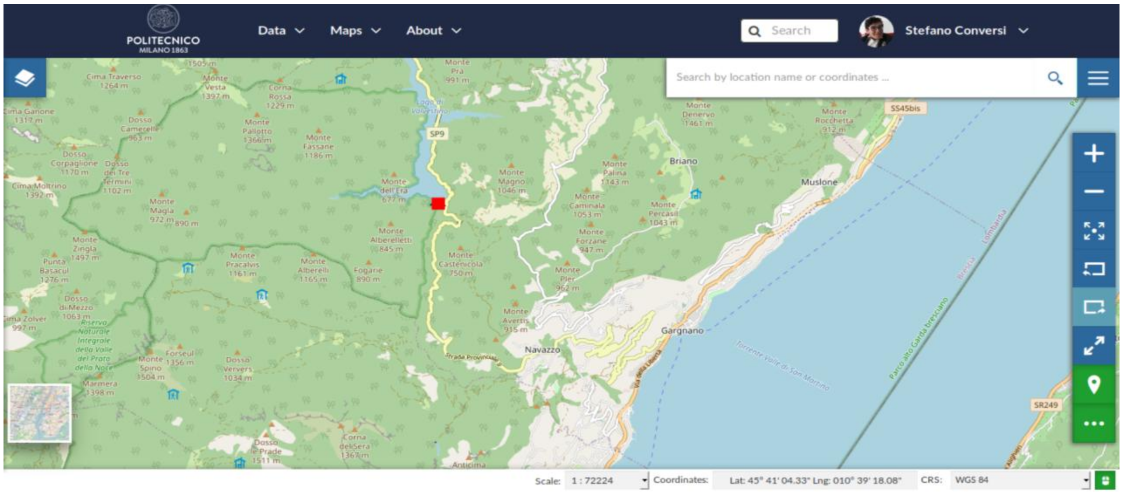

Figure 37: Implemented GeoNode platform, example of map editing.

Another relevant set of commands is the one related to the selection of layers to be displayed in the map (icon in the upper-left part of the visualizer); from this button, it is possible to access the whole catalog of data uploaded in the platform, so that the most suitable ones can be chosen by the users, according to their needs.

After the layer selection, as shown in Figure 38, it is possible to visualize and edit (if the permissions allow it) general layer information, such as title, layer group (if a grouped visualization is desired) and description; furthermore, another available option is the setting of layer display format, with particular regard to its transparency. The style of visualization can be deeply customized by opening the corresponding window, from which a dedicated procedure can be carried out with the need of Python coding language for obtaining more complex results. For the sake of completeness, it should be also pointed out that customization of display can also be obtained by uploading in GeoNode a .sld file containing this kind of information (built in another GIS application).

The displayed layer can then be furtherly explored by investigating its attribute table, which is complemented with a set of tools designed for granting efficiency during the analysis, e.g. filtering and ordering functions. Lastly, each layer can be paired with one or more widgets, to be created according to its content, selecting among the categories of chart, text, table and counter.

As a conclusion, the map can be saved, providing it with a title and a brief description or printed, after the selection of some layout settings.

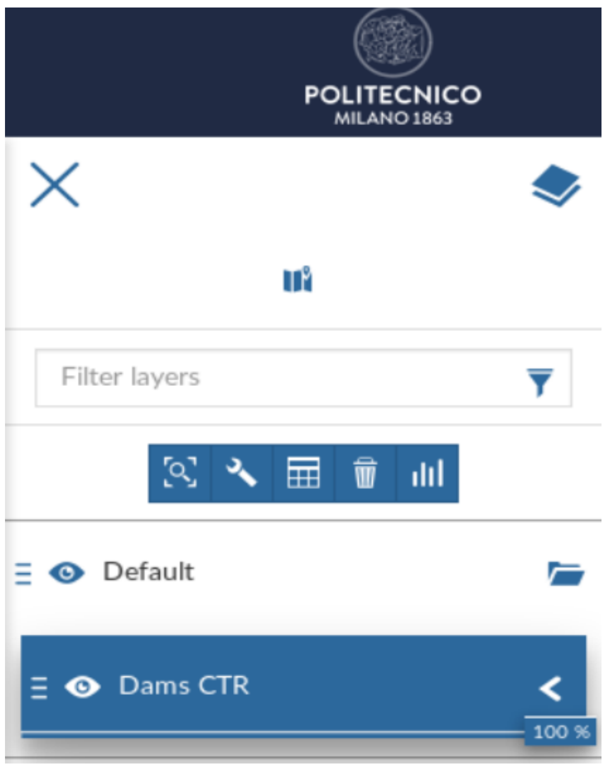

Figure 38: Implemented GeoNode platform, layer editing tools.

8.3 Strong points of the designed platform

During the development of the current project several considerations emerged with respect to the efficiency and the potential exploitation of the platform, some of which were also mentioned in the previous discussion. Anyway, for the sake of completeness, the author considers it useful to list and analyze them, in order to underline the innovative and practical aspects of the project.

The main points will be summarized in the next sub-sections, considering the following aspects: customizability of the platform, integrated nature of the project, dynamicity of the system, and lastly a comparison with traditional supports.

8.3.1 Customizability of the platform

First of all, it is fundamental to stress the high level of customization that is possible to obtain with the use of the addressed system. This should be considered both in terms of platform design and in terms of capability of the system to be employed in different fields of work.

As an example, as previously mentioned, the selected infrastructure consents the organization of several different profiles of users, characterized by as many sets of permissions. Taking a step further, it is clear that this kind of possibility allows the creation of a vertical platform that can actually be accessed and used by many different categories of people, ranging from local authorities to citizens; all the members will then be capable of exploiting the functionalities of the platform depending on their specific needs, finding answers in documents or visualizing data and all of this will be possible in the same environment. Trivial, but important, the use of a unique system like the designed one will lead to a better communication and management of the different steps of data processing during a crisis (simply because the decision maker, as an example, will be able to extract all information from a single source, not needing several platforms to access).

A relevant example in the field of users categories can be provided with respect to the usability of this platform for citizens. In this case, the idea is to give them the possibility of accessing a selected set of information, through simplified versions of data and, in addition, to provide specific documents directly addressed to population and focused on the good practice to be followed during an emergency. This choice is motivated by the crucial importance of self-rescue and, more in general, aimed at avoiding panic spread during a crisis; as a consequence, an educational employment of the platform (integrated both in peacetime and in emergency phases) could result in a great improvement of field conditions of work for operators and in less overwhelming conditions for people, even though obviously the psychological impact should still be taken into account. Moreover, population involvement will also be treated in next chapter, while discussing of one of the possible developments of the current project, in particular with respect to a process of critical issues reporting.

As mentioned before, the customization aspect can also be related to the field of application of the platform, considering that several kind of datasets can be uploaded in it; it is clear that the upload of diverse data will change the application goal of the platform itself. In this way, it results evident that a WebGIS populated with specific datasets will correspond to an extremely-fitting system of information to be employed in whichever field of intereat.

Clearly, the main kind of process for which the project was developed is the one related to Civil Protection procedures, with particular regard to the ones involving geospatial data analyses, but the platform represents a great instrument for developing other kinds of applications, either with or without the same frame of interest; aiming to provide an example, it is possible to refer to the employment of a WebGIS in the management process of public resources, as mentioned in the case of Lombardia region water analysis platform (chapter 3, Figure 10).

8.3.2 Integrated nature of the project

In this regard, it is possible to mention the second relevant point of the analysis, that is the integrated nature of the project. It is indeed crucial to state the innovative aspect of providing to users an actual platform, not a single instrument for geospatial data visualization or a tool for managing archived data, but an unique system that merges the two aspects. This combined approach results in an improvement for final users, who can find different kinds of information in the same platform. Most of all, the availability of connections among datasets (such as the links that were mentioned while discussing of layers and documents in the previous section) increases the usability of both the categories of data, allowing the users to combine and integrate information, in order to reach a deeper level of understanding of the considered data and, as a consequence, they will be able to use information in a much more profitable way in their framework.

Aiming to clarify this point, it is possible to give a practical example, let's imagine a simulation of a critical situation during an emergency, such as the one of this project study-case. It is possible to suppose that one of the first analyses that the control center operator must provide to the decision maker would be a delineation of affected areas, complemented by information on areas that would possibly be involved in the event evolution. At this point, the operator could first of all create a map superimposing different layers such as the ones related to the flooded areas and the infrastructural and built environment ones; simply by analyzing this map it would be possible to identify which areas are actually prone to be damaged in case of event occurrence.

Among the documents associated to the considered layers, the operator would then find the "Cascade event" scheme (Fig. 39), that was designed by the author aimed to synthetically describe the possible evolutions of the crisis and point out some other crucial aspects that could have not been investigated in a first moment, all of this with specific reference to a seismic dam crisis.

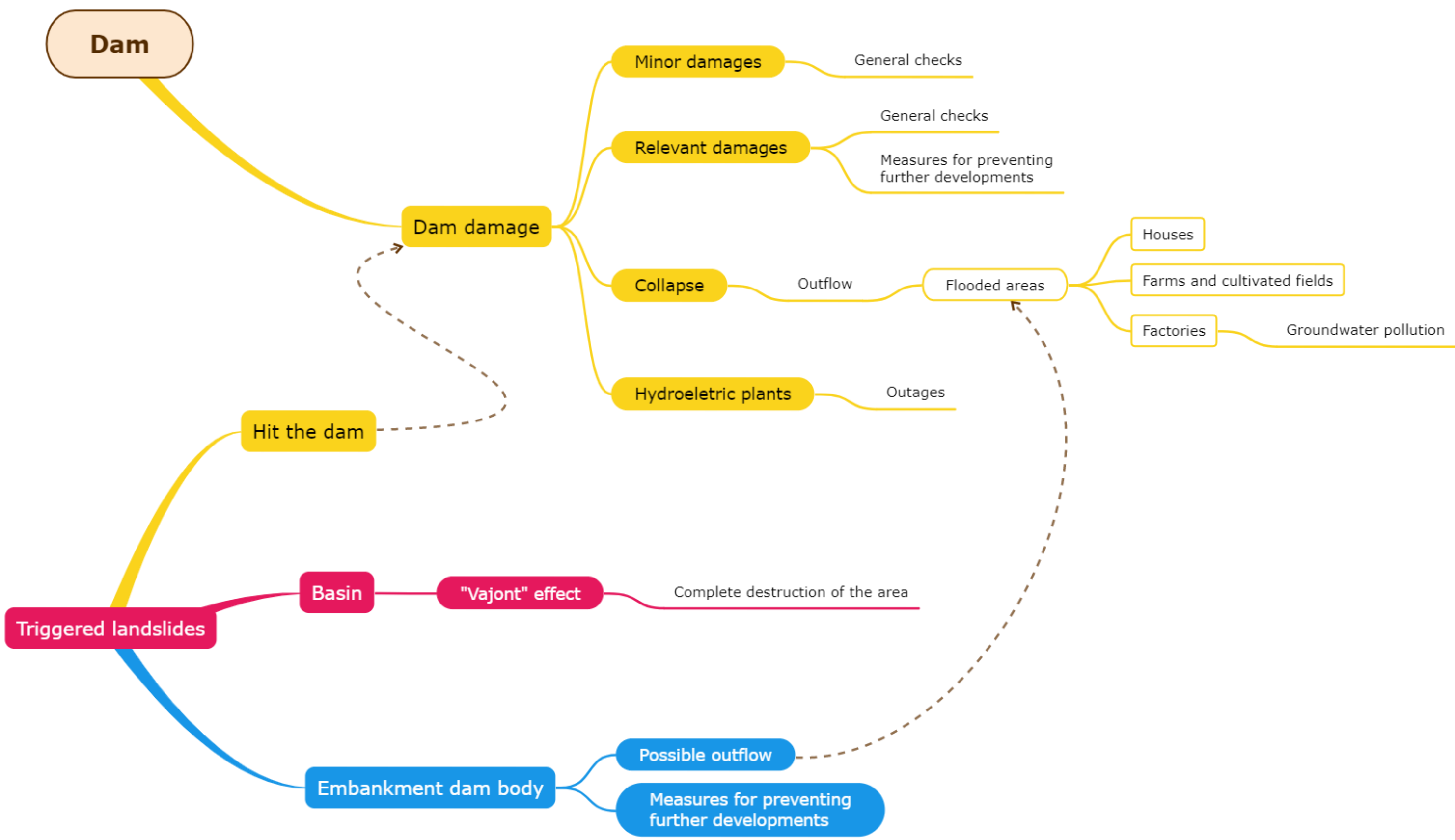

Figure 39: Diagram of cascade event chain representing the possible evolution of events triggered by a seismic input in the surroundings of a dam (drawn by the author).

On this basis, new layers can be superimposed and new areas at risk can be recognized, maybe considering a different hazard with respect to the original one. In conclusion, the simulation could evolve with a check on the uploaded official Civil Protection Contact scheme (Prefettura di Brescia, 2019), so that telephone numbers of the involved municipalities can be retrieved and local authorities alerted, before the actual occurrence of the event, increasing the efficiency of mitigation procedures.

8.3.3 Dynamicity of the system

The third relevant aspect of the project to be analyzed is the dynamicity of the system, that can be intended as its capability of constant evolution. It is indeed possible to observe the possibility of modifying it, especially with respect to datasets, i.e. in case of availability of more recent and accurate versions of some data. Furthermore, the visualizer itself is quite dynamic and allows the different users to build different maps on different areas of interest, as already mentioned. Another comment that can be added in this context is the possible expansion of the project by associating it to a smartphone app devoted to data upload, capable of improving the exchange of information and make the whole system more versatile, complementing it with a mobile style of usage; this possible further implementation will be discussed in chapter 9.

8.3.4 Comparisons of the platform with traditional supports

Lastly, it is worth to mention the innovation that the project platform introduces in its practical application context, with particular reference to older instruments used in past. The main noticeable comparison is the one regarding cartographical representations of emergency plan, such as the ones contained in PED attachments (Regione Lombardia, 2020). Firstly, it should be pointed out that the proposed system can have outcomes that might result coarser than the ones present in traditional, static maps, especially if data are coming from surveys during an emergency. Nevertheless, the platform maps are much more exploitable, thanks to the possibility of customizing them (as discussed before). Furthermore, traditional maps are capable of representing a static situation, not allowing analysis on areas that are not considered, and most of all only based on forecast or event scenarios, while the introduction of real-time data coming from the field will let the operators create digital maps that are actually representing an updated situation and this obviously will be traduced in an improvement of emergency management. Finally, it can be interesting to observe also that even though the WebGIS platform is meant to be used principally on computers, it can anyway be used to create and print maps, such as the ones foreseen by the PED.

8.4 Project integration into the context of PED application

In this paragraph, a brief example of integration of the project platform into PED application workflow will be presented. It is possible to refer to Figure 40 cascading event fishbone diagram, that was produced with the aim of highlighting the correspondences between the phases of a possible emergency (and the specific data that can be needed for each of them) with the datasets uploaded into the project system. Specifically, the mentioned diagram was built in order to describe a situation in which the outflow (actually the one due to collapse) was triggered by the combined action of earthquake and re-activated landslides on the catchment area.

It should be noticed that the graphical representation is specifically meant to cover topics related to the emergency phases, giving also some hints for the post-emergency ones, but neglecting the pre-emergency assessment. Nevertheless, it is clear that also in this aspect the use of the designed platform could be fruitful, thanks to the several sets of information that can be retrieved and employed (e.g. considering as a reference involved area characterization through historical records for earthquake and hydraulic conditions assessment, two topics present in PED and *Quaderno di presidio territoriale*, clearly accessible through the platform).

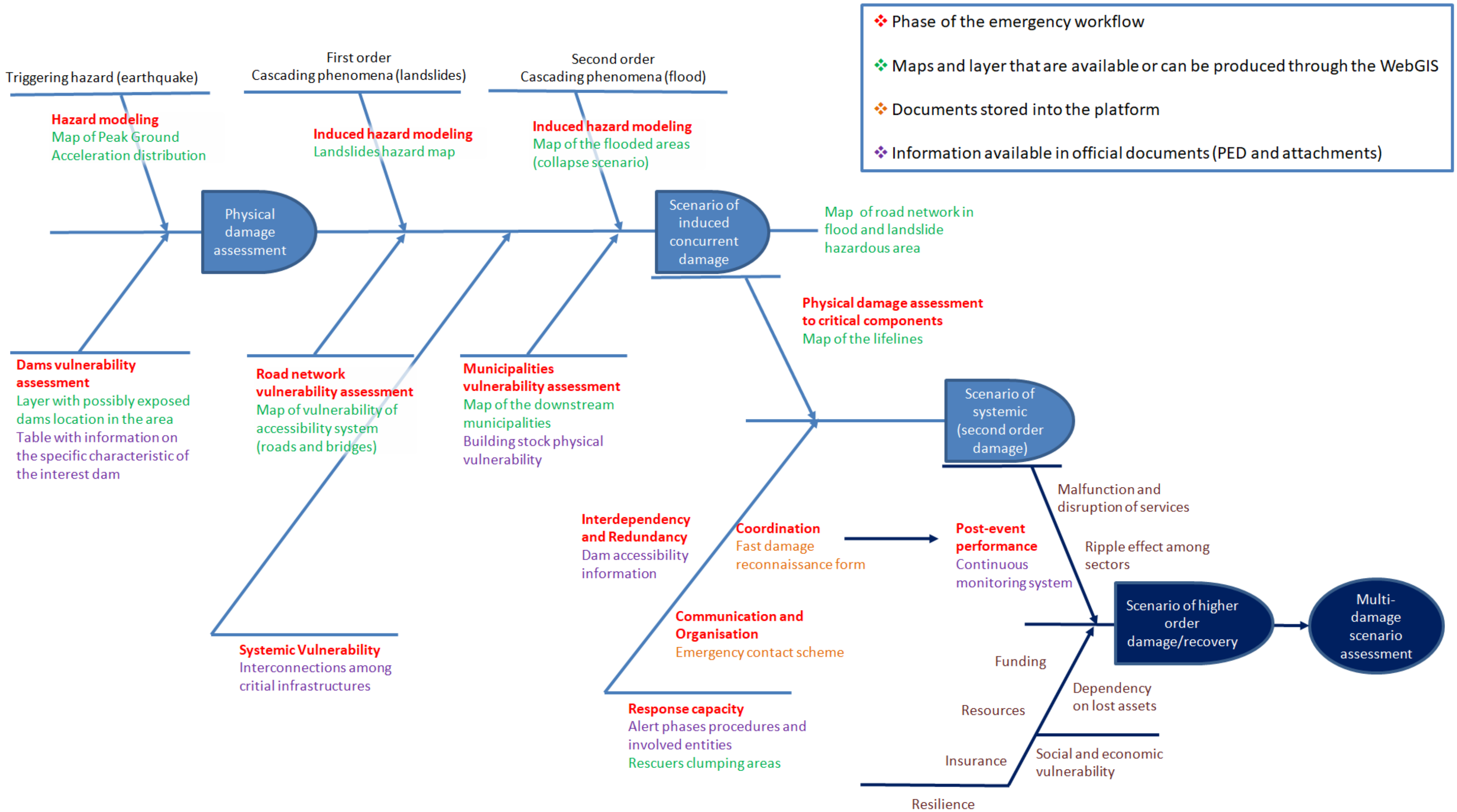

Figure 40: Fishbone diagram representing the integration of the project platform in Civil Protection procedures, adapted and integrated by the author from *Service to support earthquake dam safety inspection, study case of Campotosto (AQ)*, (Conversi et al., 2021).

First of all, it is possible to observe that in the scheme the different phases of emergency management are paired with one or more contributions available on the platform and, as it is clarified by the legend, each of them was written in a different color considering its original source: green for layers and maps that can be produced within the WebGIS, orange for documents stored in the archive and purple for additional information that can be retrieved in official documents such as PED and related attachments. Obviously, given the fact that also official papers were uploaded in the system, all of the previous listed material can be found (or processed, in case of geospatial datasets) on the platform.

It is relevant to state that clearly what can be achieved through the analysis of datasets available on the platform cannot under any circumstances substitute a direct survey on field. What can be done following the presented scheme is to merge information and data coming from different sources, in order to select areas that will plausibly be affected in a more severe way with respect to others. This will correspond to a better focus on which resources can be allocated, establishing a sort of priority-setting. Even during an emergency this will help, trying to concentrate efforts as much as possible in the most critical situations, obviously without disregarding zones that anyway have been involved, even though in a less intense way.

Obviously, the actual employment of the proposed system is related to the kind of data that are uploaded in it and it can range from qualitative analysis for a simulated event (in order, as an example, to produce an intervention scenario) to a real support to operators in case of data coming from the field during an actual emergency (obviously in this situation the results will be leaded by the information obtained from the field and they will be as reliable as the incoming information).

Moving to the detailed analysis of the fishbone diagram, a first step can be the study of the seismic input. In order to identify the main involved assets of interests in terms of dams, it is important to plot the Peak Ground Acceleration distribution, that, depending on the considered event, can be calculated (knowing magnitude and epicentral locations and applying a chosen attenuation law) or taken from an official source, such as *Istituto*

Nazionale di Geofisica e Vulcanologia (INGV), whose web-archive ITACA (*ITalian ACcelerometric Archive*) contains all information on real-time recordings of seisms (Luzi et al., 2019). This input hazard can then be combined with the layer related to dams location in the area of interest and in addition, a synthetic description of the dam characteristics can be found in PED tables (i.e. Table 2).

After this first contextualization, it is necessary to perform a physical damage assessment and in this case the Civil Protection operator that is supposed to use the platform could retrieve useful pieces of information from several available geodata; as mentioned before, the outcomes of these first analyses should be considered as a general procedure in order to identify some areas of interest prone to be damaged and they should be complemented with more detailed surveys in the field that will be in every case necessary to understand the real conditions.

As previously introduced, the hypothesis considered in this work is related to an earthquake hitting the area of interest, which can trigger some landslides (first order cascading phenomena), that can be identified through landslide hazard maps. Obviously, these sub-events can affect also other systems apart from the dam one, such as roads, which can also be represented in terms of their vulnerability to disruption.

The supposed event evolution leads to the dam collapse, as a result of the combined actions of earthquake and triggered landslides, resulting in the flooding of downstream areas reported in the corresponding layer, according to Civil Protection scenario (Prefettura di Brescia, 2019).

Another relevant information to be considered is the physical vulnerability of downstream municipalities that could potentially be affected by the considered sequence of events. As it is possible to observe in the scheme, also in this case, information coming from two different sources can be retrieved in the platform; specifically, this aspect is covered both from a map point of view and from information that can be extracted by PED analysis of the area (Regione Lombardia, 2020). Furthermore, from this document also pieces of information related to the interconnections among assets and infrastructures can be recovered, addressed by the scheme as systemic vulnerability assessment, even though it should be pointed out that in this case deeper investigations may be needed in order to obtain a correct analysis.

Combining all the previous information on hazard and vulnerability it will therefore be possible to obtain results in terms of expected damages, superimposing the mentioned hazard maps to the layer containing vulnerable assets and recovering information on which areas should be more carefully considered. In particular, the scheme presents a possible output map related to the effect of landslides activation, but it can be mentioned also the possibility of producing outputs in terms of direct impact of the seism, i.e. on the building stock of involved municipalities.

On the side of damages related to landslides, a couple of considerations should be pointed out. Firstly, it should be stated that the road system can be severely damaged by the occurrence of landslides, possibly evolving into road disruptions and, as a consequence, in a further difficulty for the operators to reach the involved zones. Landslides then should be also considered in terms of their interactions with flooded areas, because, even though it can be seen as a rare event, the combined action of these two elements can result in a much more powerful event hitting the territory. Furthermore, in some conditions it can results in the obstruction of channels occupied by flood water, that might evolve in a further increment of water pressure and, as a consequence, increase damage levels.

The subsequent aspect suggested by the reference diagram is more related to the operational side and on the organization of field interventions. First of all, the study of possible damaged critical infrastructure is required, that is actually very important in a real case, in order to estimate the possibility of having disruption in services to population (e.g. water or energy supply).

The different pieces of information addressed along the current section are intended as site-related conditions that can be acknowledged by the user by analyzing the appropriate layers available in the WebGIS; in order to clarify this point, in Figure 41 an example of a simple map that can be produced within the project environment is shown, in the case of comparisons between flooded areas and electricity supply network (performed with the aim of identifying areas possibly interested by blackouts due to the occurred event).

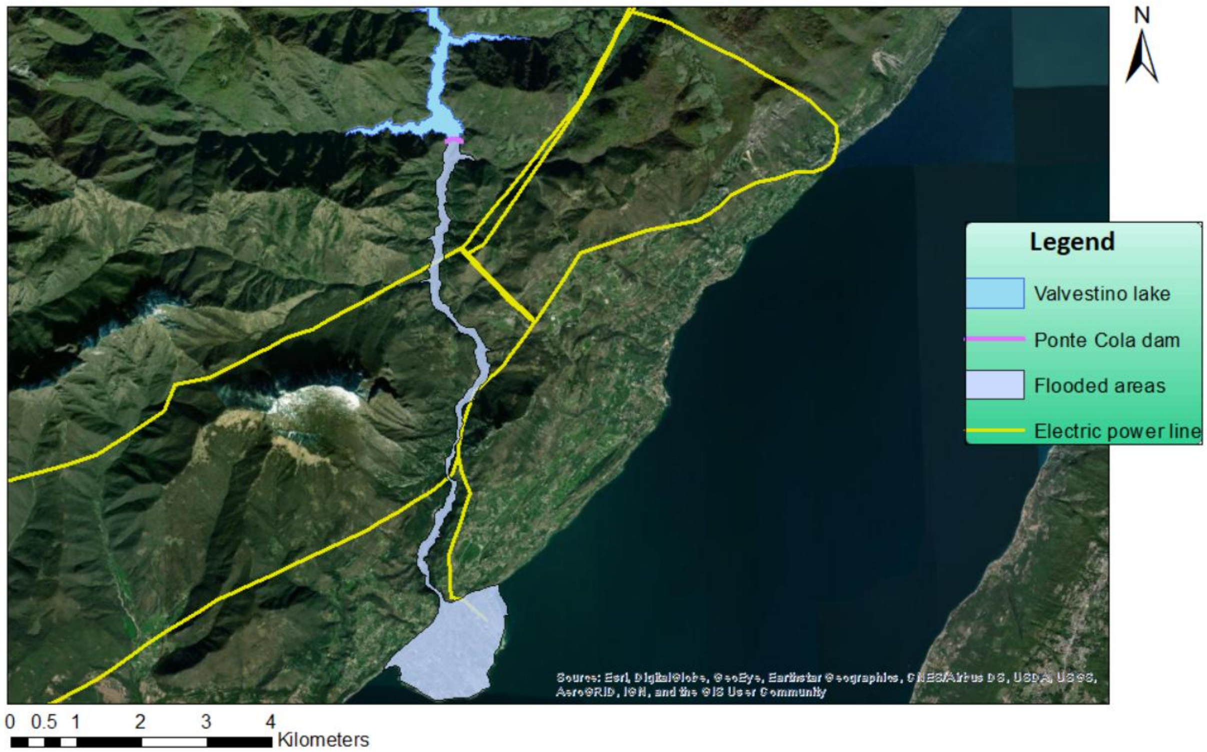

Figure 41: Example of a map achievable within the project environment.

It results evident that this kind of analysis will also be very useful for field operators, in order to have a clear idea on the conditions in which they will work during the intervention phase and, more important, through this knowledge they will be capable of preparing in the best possible way the support for citizens.

Another needed assessment on potentially damaged infrastructures, as previously mentioned, is the one related to the road system, with particular reference to the accessibility of the involved dam; clearly, the study of road network is crucial also for understanding the possibility of reaching the different areas and furthermore for individuating locations characterized by poor redundancy in this context. Indeed, if a municipality presents a single way of access (quite typical in mountainous areas in which dams are located) and this way (road or bridge), is destroyed by the event, the population will be blocked and, most of all, unreachable by land vehicles, increasing the complexity of rescue operations. Anyway, as shown in the scheme, this kind of information is pretty detailed in PED (Regione Lombardia, 2020).

Going on with the practical activities, it is also important to analyze elements related to the response capacity of areas and involved population. Furthermore , on this aspect, it is crucial to have a specific and complete workflow to be followed for emergency procedures; this stands true both in terms of lists of actions to be actually carried out to manage the crisis and in terms of involved stakeholders and correspondent responsibilities. In this case, the project embeds the established workflow that is presented in PED, but also additional information on the specific grades of alert and processes to be completed in case of activation, coherently with Civil Protection plans (Prefettura di Brescia, 2019). Another document that is provided through the platform in this field is the localization of relevant areas for emergency management and of the so-called rescuers clumping areas, fundamental to be set in order to locally face the incoming issues (Regione Lombardia, 2020).

Then, it is also relevant to provide to the operators and more in general to the whole set of people that are involved in the crisis for various purposes, a clear and effective communication scheme, in order to improve cooperation among the stakeholders. Specifically, this flowchart was retrieved by *Documento di Protezione Civile* and uploaded in the platform as an independent document, in order to increase its effectiveness (operators would not need to check the entire original document for assessing information).

Lastly, another set of documents was made available on the project platform, specifically devoted to improve the damage reconnaissance investigations in the dams sites. In particular, an interactive form was built on the base of official documents describing the set of required procedures for assessing dam behavior during the emergency and leading, as a consequence, to the activation the most appropriate level of alert. The form was integrated in the system with another document describing its capabilities and the way of employment, specifically addressing how this support takes place within the emergency workflow. All the details on this topic will be discussed in next section.

In order to avoid possible misunderstandings, it is to be underlined that even though the project study-case is focused on a dam-collapse, clearly implying the complete disruption of the structure, the employment of the damage reconnaissance form is assumed. Indeed, it is believe of the author that in-situ data collection procedures could be performed in a preliminary phase, before the actual collapse, and so also in the considered case, the use of the proposed form would cover a relevant role.

For the sake of completeness, it should then be reported that the last part of the fishbone diagram presented in Figure 40 cannot be seen as exactly matched by the content of the platform. This is because the involved operations (represented in dark blue and brown in the scheme) are mainly related to the post-emergency phase, so not properly to the real-time management of the crisis that is the focus of the project.

Anyway, at least for the analysis of post-event performances the continuous monitoring system, PED descriptions may represents a first step and, if conditions should require it, also a second employment of the Fast damage reconnaissance form could be integrated on the operational side.

8.5 Fast damage reconnaissance form and measures for improving field surveys

8.5.1 Introduction and potential benefits

In the context of enhancing emergency management procedures in case of an earthquake hitting a dam, one of the most critical aspects is related to structural conditions and, in consequence, to the possible events evolution lead by failures. In this field, the main resource is the collection of evidence and information onsite, that should be made by the owner of the structure in collaboration with a responsible engineer and, if needed, Civil Protection. In order to speed up the procedure and boost the quality of collected results, both in term of effectiveness and accessibility of data, an interactive online form has been developed, in accordance with directives from Italian Committee for relevant dams and Ministerial ones, as it will be stated in the following. Figure 42 shows how the form is intended to be integrated with the dam surveys procedure and it can be seen as summarizing the different aspects that will be discussed along the current section, based on a previous academic team-project in which the author took part (Conversi et al., 2021).

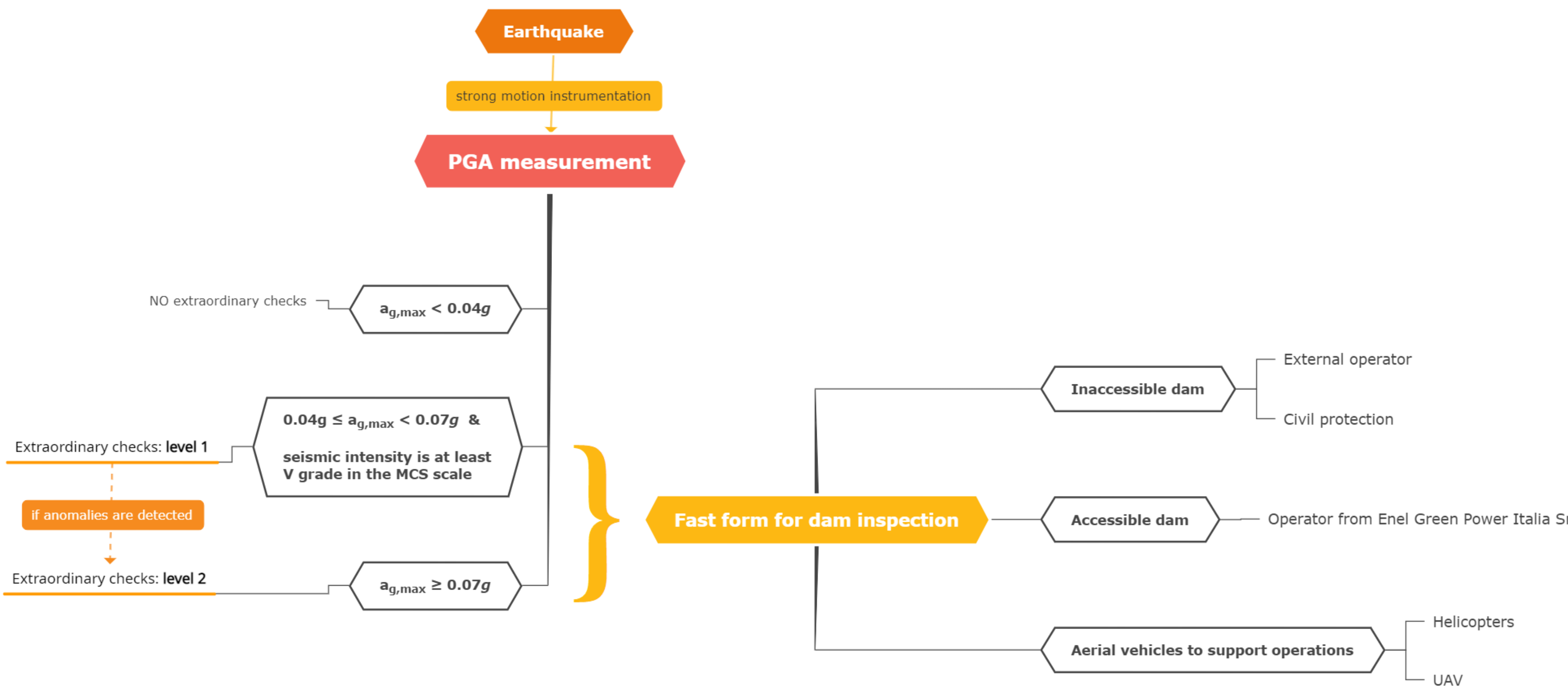

Figure 42: Workflow of dam inspections after a seismic event with integrated use of the designed Fast damage reconnaissance form, adapted and integrated by the author from *Service to support earthquake dam safety inspection, study case of Campotosto (AQ)*, (Conversi et al., 2021).

The Fast damage reconnaissance survey aims to provide in the shortest possible time span the most important pieces of information of the dams affected by the earthquake, concerning consequences and possible damages of the structure. It is fundamental to provide different sources in order to guarantee the redundancy of the information origin. The method that allows to infer the most complete amount of information is the direct inspection of the dam, so considering the necessity to provide as soon as possible the information to the control centre operators, a digitalized procedure aimed to collect data has been designed. The operator responsible of the survey is provided with an online form easily accessible through GeoNode or at the following link, which will lead to the page in Figure 43: https://docs.google.com/forms/d/e/1FAIpQLSeYQp7M2nAUEQ5F2DjFEV6ScFDTLOu3W6qO3z5uvLgn2AqWpw/viewform?usp=sf_link

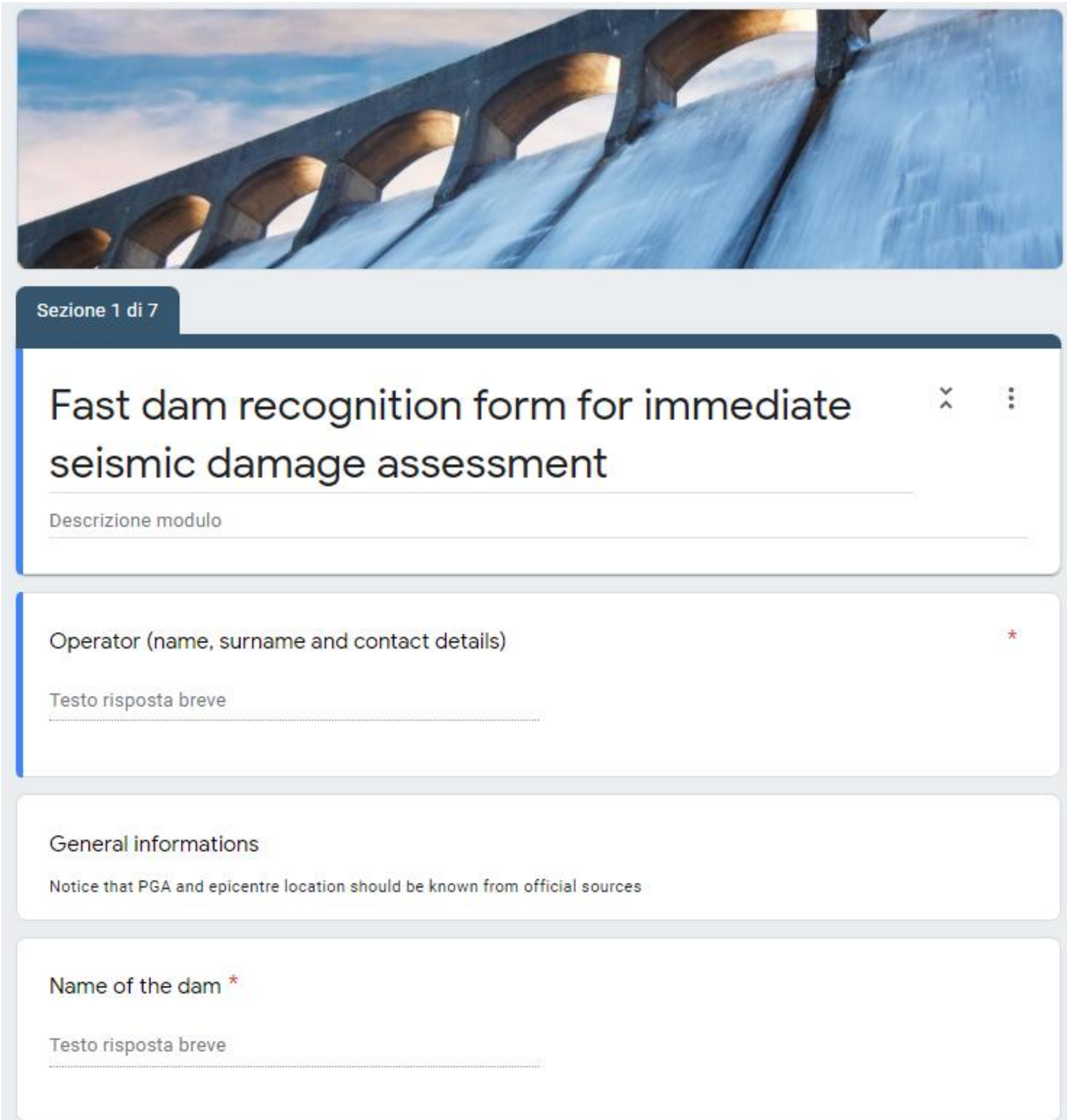

Figure 43: Interface of fast form filling.

The form must be filled by the in charge dam operator, or, if the dam cannot be reached in short time, the same operator can ask support to the Civil Protection structures operating in the territory. The power of this form is of its accessibility: it can be printed, if possible, and once completed, it can be scanned and delivered to the control center operators; on the other hand, it is available online, so it can be directly accessed, e.g., with a tablet. The operator has also the chance to insert pictures with descriptions of some particular details. Nevertheless, the form, immediately after the filling is completed, will be available for the control center operators, who will forward it to the institutional office in charge (UTD, *Ufficio Tecnico per le Dighe Milano*); then the decision maker will communicate the establishment of a specific level of alert (Pre-Alert/Enforced Surveillance/Danger/Collapse).

Some information of the seismic event should be known by the operator, who is supposed to be in contact with the INGV (*Istituto Nazionale di Geofisica e Vulcanologia*) that provides data concerning earthquake epicenter, magnitude and PGA, as detailed in section 8.5.3. The INGV has at its disposal raw data that come from the accelerometers and from seismic stations; this point will be examined after the module illustration. This fast form can also be interpreted as a starting point for the implementation of a real-time updater of the WebGIS according to the communicated level of alert, so that operators can better visualize which is the overall situation of the dam, georeferencing the information coming from the inspection of the area of interest. Results (that still will be online and thus easily collectible by control center) will be reachable also in post-emergency phases; this implies that they can be furtherly exploited as a base for back-analysis of the event, with the aim of developing knowledge on the considered site, in particular on its responses to critical events.

The whole module aims to guide the surveyor through a set of predefined questions that, in some cases, will let him access new sections, depending on the answers (i.e. details on embankments or concrete dams). It is developed in compliance with two official documents:

- The first one, which is the most important, is the Italian *Circolare dighe* in November 2017 version (Direzione generale per le dighe e le infrastrutture idriche ed elettriche, 2017);
- The second one is drafted by ITCOLD (*Comitato Nazionale Italiano delle Grandi Dighe*), and it is made by the report document of a collaborative groupwork named (translated) Italian dams behavior in of historical earthquakes, whose members are technicians belonging to MIT (*Ministero delle infrastrutture e dei trasporti*, nowadays, *e della mobilità sostenibile*) Civil Protection and Enel, coordinated by the previous mentioned Ministry (Comitato Nazionale Italiano delle Grandi Dighe, 2018).

8.5.2 Inspection procedure description

The fulfillment of this module has to be intended as a first check, dependent on the needed level of detail, defined by the PGA value and/or the presence of relevant damages. It is fundamental to proceed with other steps after this procedure, as follows: extraordinary checks are automatically activated when the threshold listed in Table 9 are exceeded.

Extraordinary checks – level 1	- $0.04g \leq a_{g,max} < 0.07g$ - Seismic intensity is at least V grade in the MCS scale
Extraordinary checks – level 2	- $a_{g,max} \geq 0.07g$ - If during extraordinary checks of level 1 damages, anomalies or malfunctions have been detected

Table 9: Tresholds for activation of extraordinary checks level 1 and level 2 (Direzione generale per le dighe e le infrastrutture idriche ed elettriche, 2017).

Moreover, some details for all extraordinary checks are provided as follows; notice that all the provided steps are compliant with the guidelines coming from the reference documents mentioned above.

- Level of detail 1:
  - Within 3 h from the event: communicate the state of damage and, if needed, the activation of level 2 survey measures;
  - Within 12 h from the event: communicate instrumental measurements collected, confirm previously assessed lack of damage and results of functionality test of the hydraulic components of the dam. If a seismic monitoring system is there, send raw data to emergenze.dg.dighe@pec.mit.gov.it.
- Level of detail 2:
  - Within 3 h from the event: communicate the state of damage and, if relevant situations are there, the owner and the responsible engineer have to suggest some appropriate measure to be taken (or already set) in order to mitigate downstream effects. Notice that in presence of damages the level of alert "Enforced surveillance/Danger" will be automatically activated;
  - Within 12 h from the event: communicate instrumental measurements collected, confirm previous damage assessment and results of functionality test of the hydraulic components of the dam; provide a first interpretation of data. If relevant anomalies are there the owner has to describe which operations have been exploited and how further checks will be performed. If a seismic monitoring system is there, send raw data to emergenze.dg.dighe@pec.mit.gov.it;
  - Within 7 days from the event: the responsible engineer must draw up an extraordinary asseveration comprehending measurements diagrams, reporting on damage entity, taken actions and prevision on the checks to be performed during the post-seismic phase. If an accelerometers monitoring system is there, a

report must be prepared in which the dams response is described according to models processing the recorded signals.

Notice that the activation of levels 1 and 2 extraordinary checks must be reported on the document *Registro delle osservazioni della diga*, devoted to record dam-observations, pointing out possible measures already taken. Then, the deactivation of this extraordinary set of surveys should be indicated by the competent institutions, even in accordance with the dam owner.

It can be lastly pointed out that the checks should be complemented in case of relevant damages (not directly leading to an outflow) by the activation of some kind of measures from the dam manager side. One example could be the decrease of the water level in the basin carried out with the aim of reducing hydrostatic pressure on the structure, so that the water weight itself would not furtherly endanger the physical stability of the dam body, as suggested from *Commissione Nazionale Grandi Rischi* in the case of 2016 event that interested Campotosto lake and its dam system (ANSA, 2017).

8.5.3 INGV data to support emergency procedures

As anticipated in previous paragraph, the operator will need some pieces of information that should come from the INGV; the most important one, as specified before are: epicenter, magnitude and PGA of the earthquake. In particular, information is acquired by the RAN (*Rete Accelerometrica Nazionale*) and all the recorded data are available in the ITACA (ITalianACcelerometric Archive) database (Luzi et al., 2019). Every station is identified with a code and moreover some helpful details are provided:

- Location (latitude and longitude, region, province and municipality)
- Average seismic shear wave velocity
- Vs30 and method used to estimate it;
- Site classification (EC8 code) 13;
- Topography;
- Morphology;

- Geological map;

In particular, for each event, the data recorded by the station are scheduled and the following information is available:

- Epicentral distance;
- Local magnitude;
- Moment magnitude;
- Acceleration with Peak Ground Acceleration (PGA);
- Velocity;
- Displacement;
- Response spectra (Fourier spectra, Pseudo Acceleration response Spectra, Displacement response Spectra)

First, these data are needed to establish which level of extraordinary check is needed and to access more precise information on shaking in the dam's surrounding. For this reason, it is fundamental that the accelerometers are as close as possible to dams, in order to provide accurate measures not only concerning the earthquake event but also e.g., for site classification. It should be noticed, anyway, that different levels of quality of data can be reached, depending on the instruments installed at the time of earthquake occurrence. Furthermore, although RAN network covers a large part of Italian territory, it is possible that in some cases a sensor results to be quite distant with respect to the epicenter and/or to the interested dam. In the case chosen as an example in this project (November 24th 2004, Garda area) the closest available station in ITACA dataset was located in Gazzino - Vallio Terme and its demise in the days following the seism should be mentioned. Actually, some other stations are available nowadays or have recorded events in the subsequent years, even in Toscolano Maderno, but still not in the period of interest of this project. As an example of ITACA dataset the chart of Pseudo acceleration spectrum (PSA), with 5% damping is reported in Figure 44.

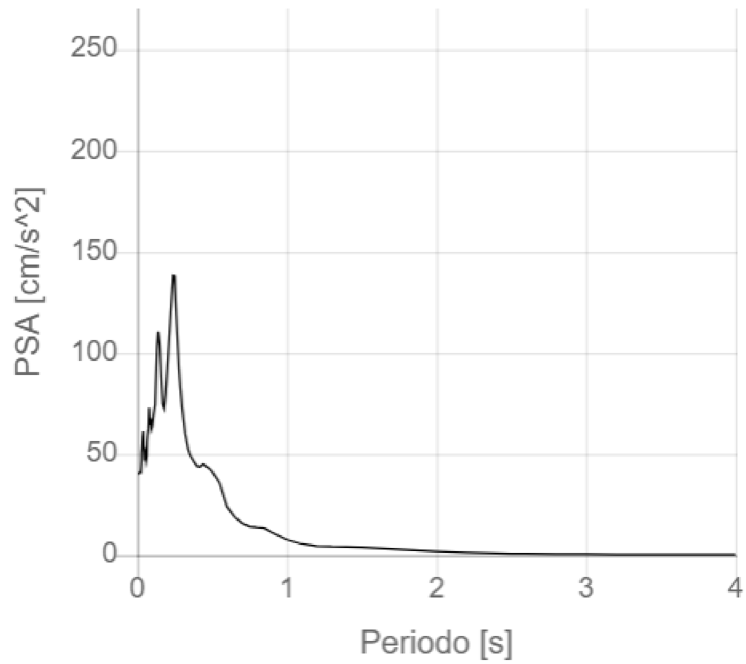

Figure 44: PSA spectrum with 5% of damping recorded in Gazzino-Vallio Terme (24/11/2004), (Istituto Nazionale di Geofisica e Vulcanologia, 2019).

8.6 Project design choices and proposed architecture

With reference to the components of a WebGIS architecture discussed in chapter 3, Figure 45 shows the proposed software integrated in the thesis platform.

In particular, the web application was built by taking advantage of OpenLayers and GeoWebCache, which consented a direct connection with the selected GIS Server, GeoServer. The application was coded in Python language and the administration role was deployed through Django admin interface. Apache was then used as a Web Server and, coherently with the results of the analysis on software spread in real application, the GIS Database was considered to be framed into the interaction between PostgreSQL and PostGIS.

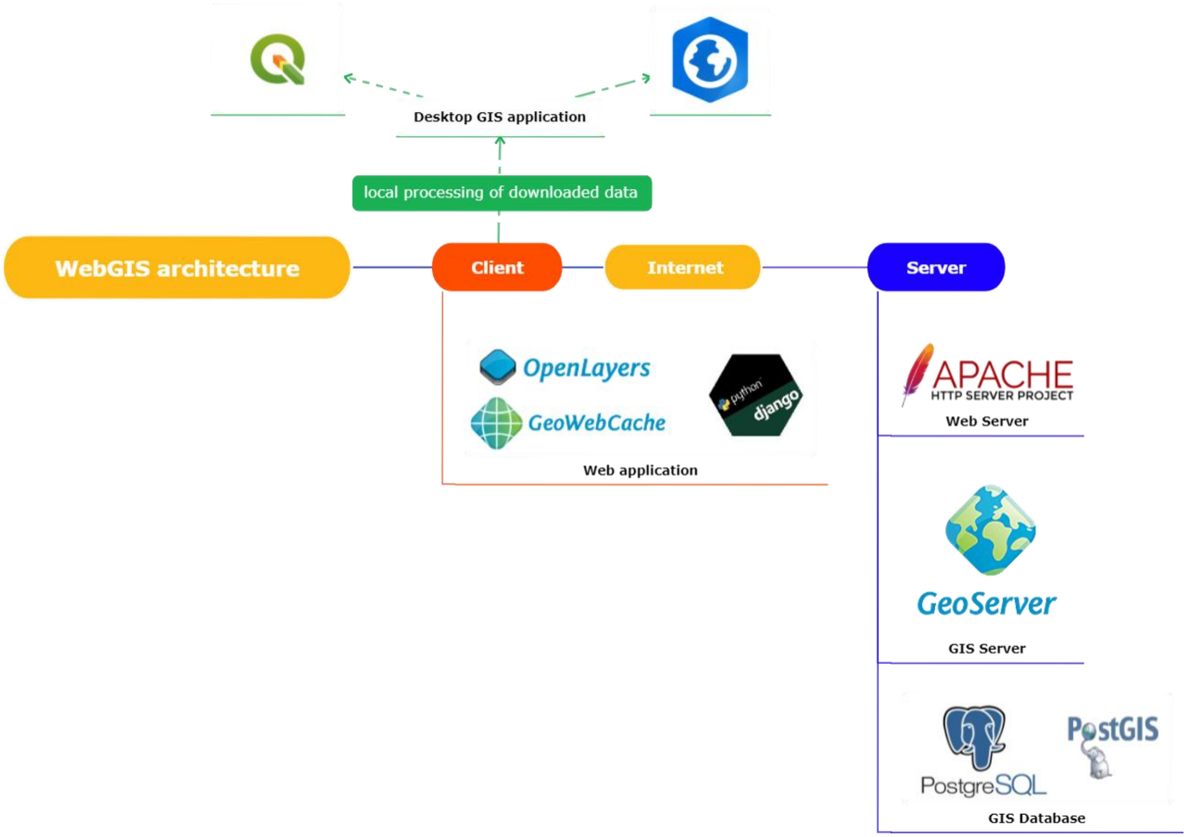

Figure 45: Scheme of the proposed architecture for the designed platform (drawn by the author).

8.7 Possible further developments and association with a secondary upload platform

As a conclusion, it could be meaningful to list a series of possible further developments that could help in refining and expanding the current project and its functionalities.

First of all, it can be suggested the integrated use of the developed platform and a desktop GIS. This would lead to the possibility of analyzing and, most important, displaying results in a more complete and efficient way. Indeed, even though GeoNode environment allows a good variety of customizations, it remains a platform that needs a quite deep knowledge of Python coding language, in order to reach the desired outcomes, e.g. from the graphical point of view. In this regard, using the platform as a sort of first step for localizing data and subsequently download them in order to be able to work on that on an more user-friendly system could result in an improvement of the procedure, with specific reference to the graphical aspect and map production; obviously, a deployment of this kind would require the user to be capable of managing other GIS tools.

Still on the field of different systems integration, another possibility could be retrieved in the use of a Dashboard platform, e.g. as ArcGIS one (ESRI, 2021). This kind of tool consents the organization of a WebGIS as a single-page application, meaning that once the user accesses the website, all the data will be directly available in the main page. Usually, the page layout is characterized by the presence of a main interactive map in the middle, surrounded by a set of icons and windows in which information on displayed data or linked datasets can be retrieved. This kind of approach could actually result in a profitable evolution during the emergency phase, while with respect to the archive-function it offers less functionalities that the GeoNode platform, but still it is possible to make the hypothesis of co-existence of the two different platforms cooperating in different aspects of the workflow. Indeed, the suggested Dashboard organization could help to focus on the considered area, providing in an effective way all suitable information, with the results of boosting the usability for operators, who can monitor the situation in a more integrated framework. This concept is actually corroborated by the effective integration of Dashboard platforms in real crisis management applications, such as

Catalonia Civil Protection one, based on the analysis of Francolí floods occurred in October 2019 (CECAT - Centre de Coordinació Operativa de Catalunya, 2021), developed within European Commission LODE project. In Figure 46 it is possible to observe a map showing the distribution of precipitations during the considered event, paired with information on cumulated rainfall and affected assets (in terms of involved municipalities, but also with details such as total length of roads and number of telephone lines affected); this example clearly proves the effective integration of data that can provide a powerful support to emergency management procedures.

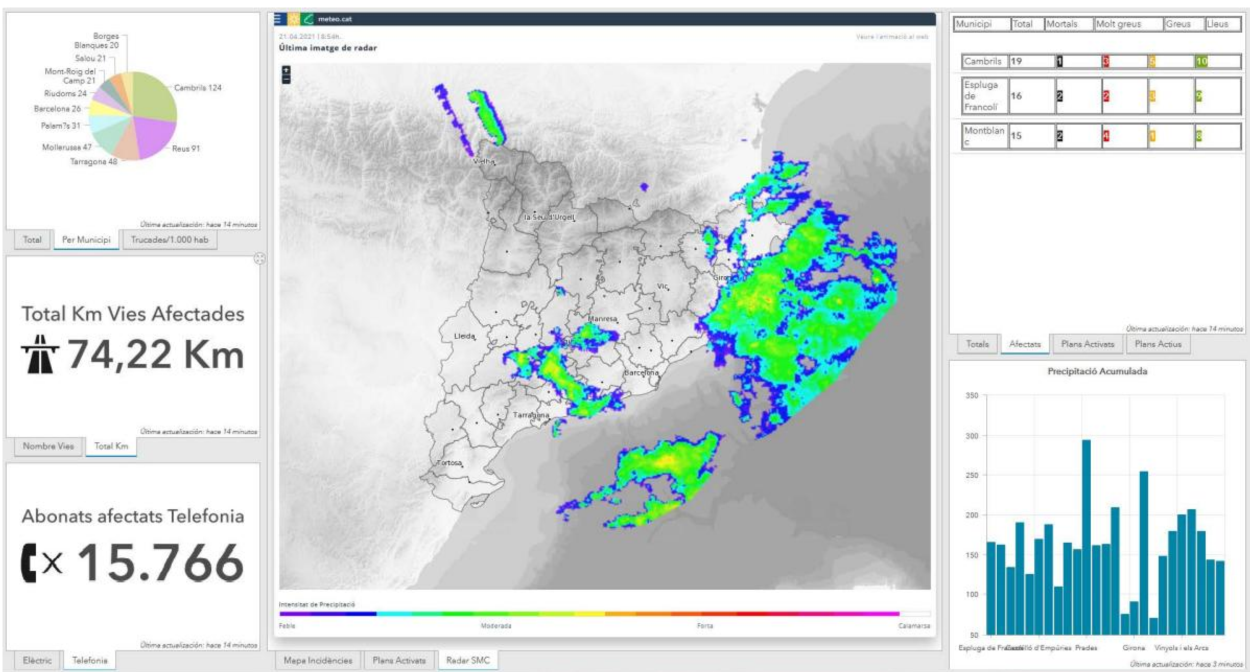

Figure 46: Dashboard application, example of Catalonia platform for flood monitoring (CECAT- Centre de Coordinació Operativa de Catalunya, 2021).

Actually, Catalonia example provides another important topic on which it is useful to focus, that is "live" information flow during a crisis. This can be represented by the near real-time upload of data or the integration of tools that can automatically provide to the operators (through the WebGIS platform) details on the ongoing event. It is reasonable to suppose that this kind of functionality could be complemented to designed platform, so that the platform could achieve a further level of usability in real Civil Protection applications. In this field, another possible evolution could be retrieved in the concept of linking the platform to one of the institutional monitoring services of natural indices. A practical example in this case can be the one of meteorological forecasts and field measurements coming from ARPA (*Agenzia Regionale per la Protezione dell'Ambiente*), covering parameters such as hydrometric levels and cumulated precipitations that could be accessed and requested in real-time (ARPA Lombardia, 2021). It is clear that, if an integration of these datasets could be possible in the project platform, then the operators using it would have at their disposal some additional set of useful information in order to understand how the situation may evolve and, furthermore, which are the in-situ conditions. Going a step further, another official service that could be associated to the platform is Copernicus' EFAS (European Flood Alert System), an instrument built in order to support preparatory actions with respect to possible flood upcoming in European territory (Copernicus, 2021). Actually, the information reachable through this system are very detailed and could provide a powerful tool for improving quality of Civil Protection procedures and, furthermore, even though for now only EFAS official partners can have a complete access to the real-time datasets, the organization provides also OGC compliant web services that could be integrated in pre-existing platform, opening the possibility to future integration systems like the project one.

The alert concept pointed out in EFAS could actually be furtherly addressed in this project by considering a possible integration with a system capable of directly connecting control centers with involved population. As an example, it is possible to imagine a situation in which the evolution of monitored parameters (either from additional services such as meteorological ones or from field surveys or monitoring instrumentation in case of dams) shows a clear approaching of critical conditions, that may result in an upcoming event. In this case usually some alert procedure should be enforced, in order to make the population aware of the possible event evolution and, even though some sirens are actually present in the study-case territory, a more refined dissemination of the alert could be achieved by using other means of communications, such as social networks or directly sending SMS to resident people, as shown in a simulated screenshot in Figure 47, coming from the previous project by the author on Campotosto (AQ) lake dam system (Conversi et al., 2021).

Figure 47: Fac-simile of Civil Protection alert via SMS (Conversi et al., 2021).

A last comment can be devoted to the possibility of inserting historical series of data in GeoNode; this environment consents indeed the upload of same datasets covering the same areas, with a different temporal reference. It provides also with the possibility of displaying the evolution of the considered data within the selected time span, consenting a new level of analysis not only related to the spatial aspect, but also to the variation of responses of a territory along (as an example) decades. This aspect can be seen as useful in the project application considering the aim of characterizing the interest site in peace time, because it would help users to understand both the aspects of territory behavior evolutions and, most of all, to visualize historical records in the map, allowing a specific study on this aspect that, as it was introduced in chapter 6, is crucial in order to understand what kind of events affected the area in past and, as a consequence, estimate expected recurrence of specific intensity events. Obviously, the usefulness of this possible development depends entirely on the quality of data and on the time range that they would cover, but in any case, the suggested function can be useful also in other exploitations or paired with other official sources, such as CPTI (*Catalogo Parametrico dei Terremoti Italiani)* for the study of past earthquakes in Italian territory (Istituto Nazionale di Geofisica e Vulcanologia, 2021).

By way of conclusions, a last aspect of the current project can be pointed out. Indeed, during its development two main steps were addressed in the design phase, firstly the implementation a prototype of base framework capable of matching Civil Protection needs, shown until this point, then a proposal for expanding it was built, with the aim of supposing the integration with a second platform, principally devoted to crowd-sourcing data upload. This idea will be deeply addressed in next chapter along with corresponding feasibility analysis and additional considerations, but, as mentioned, only the design of this possible expansion was carried out, so it may be interesting to declare as a last suggestion for future development its actual realization and integration within the proposed framework.

9. Proposed expansion for the project system: integration with an crowd-sourcing application for data upload

As anticipated in previous chapter, the possibility of expanding the project was considered. Although not implemented, the hypothesis of this expansion brought a series of comments and considerations that could be useful to point out and discuss, as it will be shown in this chapter, in order to set up a general scheme that might constitute the basis for the future actual development of the project.

The main core of the current proposal is the interest in enlarging the “vertical” employment of the project platform, consenting a wide usability for all three identified levels of competence of the users, as outlined in Figure 48: people working in emergency control center, external technicians, population (and field Civil Protection teams). This additional tool will be constituted by a mobile application, downloadable on people’s own devices and connected to the GeoNode system.

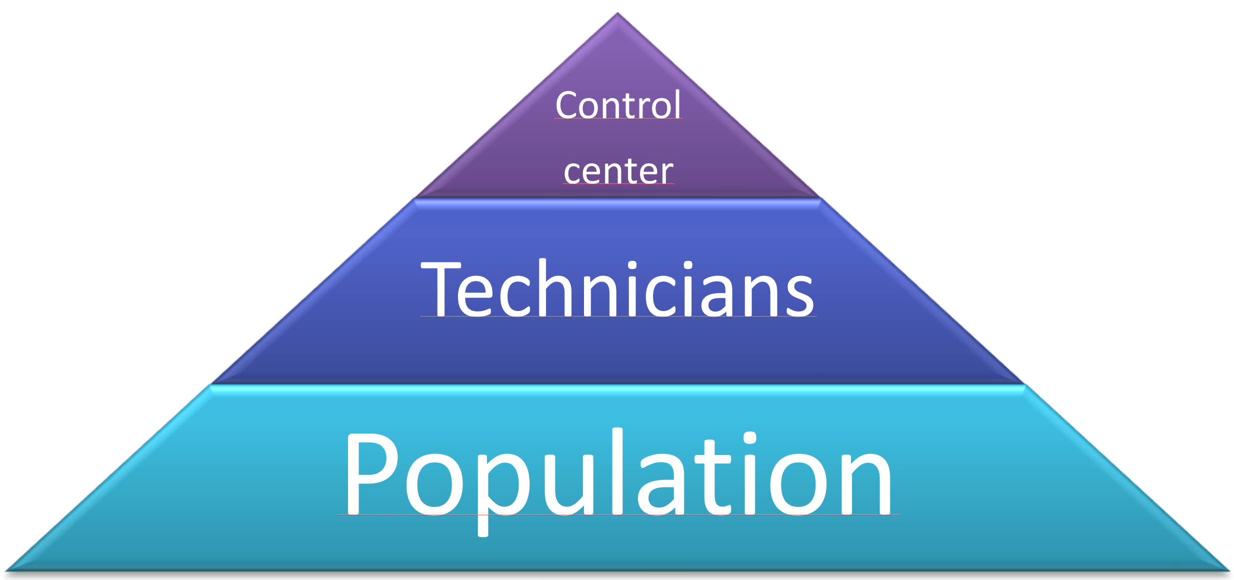

Figure 48: Pyramid scheme representing the users levels of competence within the proposed project framework.

The project platform, as shown previously, provides a great tool for supporting the different users, each of them with specific datasets and permissions to access to them, but it should be stated that its functionality is specifically meant for download operations, in the sense that even though it is actually possible to insert data on the platform, its main usability field is the one related to the consultation and analysis of the given datasets. The expansion focuses instead on the complementary phase of information workflow, the upload one.

Indeed, its role will be the one of connecting the different users, but in the opposite direction with respect to GeoNode platform, consenting a flow of information from lower levels to the one of Civil Protection. Specifically, two main ways of addressing this point were identified, one for citizens and the other for external technicians. The possible information coming from the two different classes were distinguished too, identifying in the uploading of technical data coming from field surveys the contribution of external technicians (especially related to peacetime operations), while citizens were supposed to use the application as a tool for reporting critical situations happening during the deployment of an emergency. Clearly, in order to be fitting in the project environment it will be required to georeference both types of information; this procedure should be carried out by the application itself and actually this was the main feature on which an analysis of already existing apps was performed, with the final goal of identifying one or more suitable environments for the possible implementation of the proposal.

In the following paragraphs a detailed discussion on these aspects will be presented and paired with possible criticalities.

9.1 Employment of the mobile application in peacetime: External technicians

The concept that lies behind the direct involvement of external technicians in the considered workflow is to be able to improve (both quantitatively and qualitatively) the extent of available datasets in the GeoNode platform. In this way, via direct field surveys, the goal of updating data can be achieved, increasing as a consequence their reliability.

Furthermore, apart from the obvious considerations about the improvement of the archive, these new data may result to be usefully employed even during emergency phases (clearly, it will depend on the kind of data). As an example, it is possible to suppose the involvement of a geologist that is carrying out the characterization of a site belonging to area of interest for its own studies. Then, through the app it will be allowed to share the retrieved information (let's imagine it is about the identification of a possible dormant landslide) with Civil Protection, so that the result of this study can be included within the datasets related to landslide hazard; in case of a real event this piece of information may result useful for operators, e.g. improving the emergency management and so avoiding losses.

Once the general concept has been presented, it is meaningful to point out some possible comments on the feasibility of the implementation of this information flow in the current project.

Addressing the main task of data transmission, the supposed application will allow the user to select a point on the map, basing on GPS signal of its device if it is to be referenced in the current location or simply by recalling the point to which its analysis was referred, and characterize it through the insertion of all information coming from its study. Specifically, the application will consent the filling of a pre-built metadata scheme, that will include pieces of information on the author, on the kind of analysis performed and, obviously, on the results.

The establishment of a specific metadata scheme will result into a useful tool for organizing all the data coming from the field in a similar way, avoiding as much as possible confusion and lack of information that could compromise the quality of datasets and their usability. In addition to this, information contained in the mentioned scheme will also be used as a base for drawing the attribute table of the uploaded layer, once the information will be transmitted to the project platform and, furthermore, it could also be possible to insert a mandatory field in which the technician must specify the macro-area of interest of its survey, so that the final result can be stored in the correct category of layers, within the twenty shown in the project chapter. Lastly, the submission of a document (e.g. a *readme* text) to better explain the content of the collected data and their possible employment could be suggested or required to the user.

Another aspect that must be carefully addressed is the one of data reliability; indeed, it would be a nonsense to accept incoming information without checking the source or, better, the quality of data. This tricky point may be faced with the involvement of a team of experts that can cover the known areas of interest of the project and have the suitable expertise and authority, in order to decide whether the data can be included in the platform or not, meaning that their upload process should be blocked. Obviously, the involvement of some experts would present some complexity, first of all with respect to the selection of the most eligible profiles; a possible solution to this issue might be the employment of experts already belonging to the Civil Protection framework such as the ones that represent the fourteen support functions required by *Augustus* method (Galanti, 2008).

The work of this new group of people within the concerned parties will represent a sort of intermediate step between the data collection and transmission through the app and the actual upload into the project platform, that in case of positive outcome of the experts board can be performed by a technician.

Still on the field of information flow, it is possible to assume that not all the studies are related to point sources, but they may be devoted for instance to the characterization of an entire area. Supposing that the field expert is not capable of submitting an areal dataset through the application (that should anyway be possible, for skilled users) it can be pointed out the need of another intermediate stakeholder who can be responsible of georeferencing the information coming from the field, in order to have a representation as consistent as possible to the ones that are present in the WebGIS. Clearly, also in this case the acquired data should be verified by the Civil Protection experts, so it seems logical to suppose that firstly the information will arrive to this group of people and only later, if validated, they will transmit it to the GIS technician in order to perform the georeferencing and the final upload into the WebGIS, otherwise a semi-automatic upload procedure could be implemented, too.

Furthermore, it should be considered that another kind of information may be only textual ones, actually not related to a point, but simply describing some conditions of the area of interest (e.g. PED and its attachments); in this case, obviously the workflow could be refined with the possibility of submitting documents directly to the stakeholders in charge of approving them and, subsequently, uploaded into the project platform through the "traditional" function provided by GeoNode.

9.2 Employment of the mobile application in emergency time: Citizens

As far as citizens involvement is addressed, the relevant opportunity that the application is representing in terms of communication during emergency should be analyzed.

As mentioned, the main use of this secondary instrument for population will result in the possibility of reporting local emergencies or critical conditions happening in the territory. Actually, this might seem as superimposing with the already existing scheme of intervention related to the European emergency phone number 112 (Eena, 2020), but the application use will allow people to give information into a different and more efficient form. Specifically, their reports will immediately be georeferenced and they will be clearly visible on operators' maps on control center screens. In addition to this, the application will easily let people take a photograph of the ongoing issue, so that operators can reach a deeper level of understanding of the situation simply by consulting the report itself.

The subsequent actions will actually be devoted to direct interventions of Civil Protection field teams, in order to provide a practical support as soon as possible. Furthermore, while sending their reports, citizens can also insert their contact into a fixed scheme of information that the app will request, and in this way the operators will be able to direct reach them by phone, in order to improve the efficiency of their actions.

As a further evolution, the real-time visualization in GeoNode platform can be implemented, along with the possibility of “switching off” the identified punctual emergencies once they are solved or if they are verified to be false alarms, a condition that will also be addressed in the following discussion.

The combination of the mentioned aspects is the essential target that the app development aims to reach, in order to increase the quality and timeliness of intervention and provide a service to involved people even better than the one available nowadays.

A couple of problematic aspects arised while considering the applicability of this system to a real emergency. First of all, it would be unthinkable that all the Civil Protections units on the field may be devoted to the interventions in the highlighted point, exactly as it is difficult to believe that a single team would be capable of responding directly to all the warnings coming from population (obviously, supposing a good diffusion and employment of the app). In this regards a possible solution may be found into the coordinated action among different local control posts, that may organize support teams specifically devoted to this kind of operations, including Civil Protection members and volunteers, enlarging the number of available operators without decreasing the quality of other intervention procedures.

Another crucial aspect to be considered is the possibility, even though reasonably it should not be present, of people sending false information. This kind of behavior is actually not an easy task to be faced and may result in losses of time, that would relentlessly affect rescue procedures. Experience showed that usually citizens are prone to cope in the meanwhile of a crisis, but nevertheless the problem should be faced. A partial solution can be retrieved in the login procedure of the app, that may be mandatory to be performed with official credentials, such as the European laws compliant SPID system, currently spread in Italy for institutionally recognized digital identification of citizens (Agenzia per l'Italia Digitale, 2014). In this way, all the information coming from the user may result as an official declaration and, as a consequence, false statements may lead to prosecution. As it is easy to understand, this topic should be deeply addressed in case of actual development of the app system, especially taking into account the feasibility in terms of national regulations and considering in a suitable way the aspect of sensitive data of citizens, to be carefully managed in compliance with established regulations.

A last aspect that is meaningful to point out in case of population involvement (that nevertheless may result useful also in case of external expert use) is that the deep integration of an application of this kind into the emergency workflow will require a precise knowledge of the tool and its functionalities. Then, it can be imagined a sort of educational campaign of information before introducing the app in the actual procedures, in order to raise people awareness on the crucial role that they may recover in emergency management and, secondly to teach them how the system will work. Some social media actions can be performed to achieve this goal and in addition a set of online documents specifically drawn for this purpose can be made available, also taking advantage of the citizen user category of the GeoNode project.

9.3 Application workflow and involved stakeholders

Summarizing the workflow that has been discussed until now, it is possible to outline the process as shown in Figure 49**.** In particular, it can be noticed the presence of the decision maker role within Civil Protection members, aiming to represent the person (or board) in charge of taking decision on the actual management of the emergency, usually belonging to local or national institutions depending on the scale of the problem and on the considered control center of reference, as discussed in chapter 7.

Then, Table 10 shows an organized and detailed description of the involved stakeholders, specifying also the different levels of competence in which the workflow is structured, as mentioned in this chapter introduction (1^{st} for Civil Protection control center, 2^{nd} for external technicians, 3^{rd} for population and field operators).

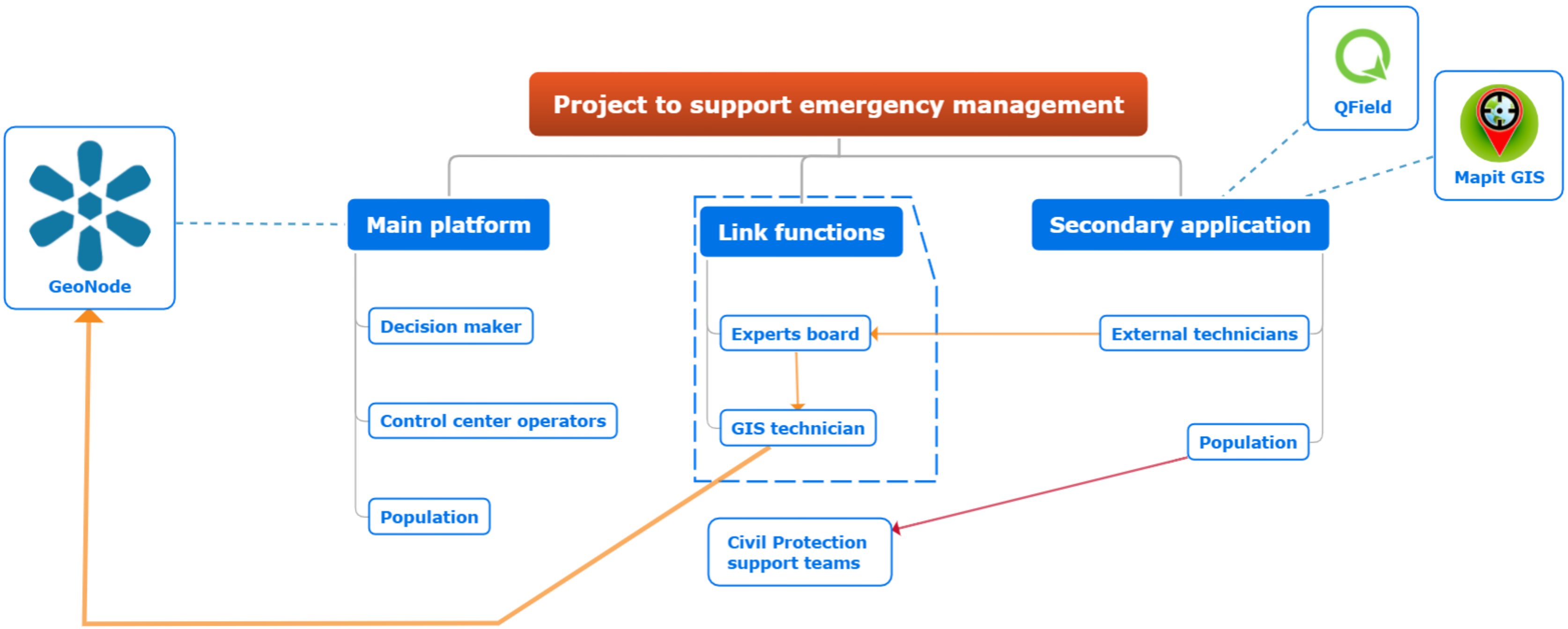

Figure 49: Workflow of designed platform and application integration into emergency management procedures (drawn by the author).

#	Level of competence	Category of users	Download from	Upload to	Activity
1	1st	**Decision maker**	/	/	Make decision on the basis of material shown by **2**
2	1st	**Control center operator**	GeoNode	/	Superimpose layers and analyze documents
3	2nd	**External technicians**	/	App (Georeferenced) Send info to **4**	Collect information and send it to the experts for validation. Must mandatory submit also metadata scheme and a document for data use/interpretation. If possible geotag, otherwise **5** will process information
4	2nd	**DICOMAC/Sala Italia (14 experts)**	Receive data from **3**	Send VALIDATED information to **5** or directly to **2**	Team of experts, role of validation of data coming from the external technicians. If valid and georeferenced, goes to **2**
5	2nd	**GIS technician**	Receive data from **4**	GeoNode	Georeferencing on VALIDATED information
6	3rd	**Population**	GeoNode (emergency guidelines)	App	Through their smartphones, people will be able to take a shot and report a critical situation
7	3rd	**CP support teams on field**	/	/	Composed by CP operators and volunteers. Check on **6** reports. Respond to critical situations.

Table 10: Activities definition for involved stakeholders in the designed workflow.

9.4 Comparison between two existing applications for the proposal implementation: QField and mapitGIS

To perform a preliminary assessment on the existing platforms that could be used to implement the integration within this thesis project, some applications available on Android Play Store were checked and two of them were selected as particularly suitable for the purpose.

The two considered apps are QField (OPENGIS.ch, 2021) and mapitGIS (mapitGIS, 2021), whose icons can be seen in Figure 50; in this section, a brief comparison among them will be presented, in order to understand their possible contribution to the designed project.

Figure 50: QField (OPENGIS.ch, 2021) and mapitGIS (mapitGIS, 2021) icons.

Both of them allow the users to see their position in a map viewer, OSM for QField, while mapitGIS offers a wider possibility of selection for basemaps (OSM, Google Maps, Bing Maps…) and when the app is launched the users have to select the project they want to work on.

The project selection is a crucial aspect, because it will let people access the environment specifically built for their needs. Indeed, these apps consent the creation of specific layers in which the users can create new points and characterize them with a series of attributes and comments. This fields to be filled can be established by the person in charge of developing the platform, so that it will contain the desired scheme of information requested to the user. As an example, it can be considered the possibility of inserting in this scheme a field for describing the kind of emergency that is being reported or the kind of survey performed by a technician. Both applications then allow a highly detailed customization of the projects and requested attributes, also with the possibility of inserting multiple choices, so that the user can be capable of choosing the content among a set of possibilities (e.g. this could be the case of technicians, who can take advantage of this function for specifying which is their field of work).

In this regard, a wise choice could be the one of building two different projects, one for citizen reports (emergency use) and the other for technicians (mainly peacetime-oriented).

Furthermore, an important aspect to be taken into account is the possibility of adding photos to the mapped point through the user interface. Indeed, this goal can be achieved in different ways depending on the considered app.

QField procedure is based in several steps, as it can be seen in Figure 51 and Figure 52 (the particular case shown is a default project, in which the user can map and characterize apiaries in the territory); firstly it will be necessary to switch from the Browse mode to the Editor one, then the user will be allowed to map the point of interest, basing on its GPS position or selecting it on the map. Subsequently, the added point can be characterized through the addition of general information, specific ones (in this case represented by the "Issues" page, that could be substituted with the detailing of the emergency, as suggested before), and lastly an image can be added, directly uploading it from camera or taking it through the application.

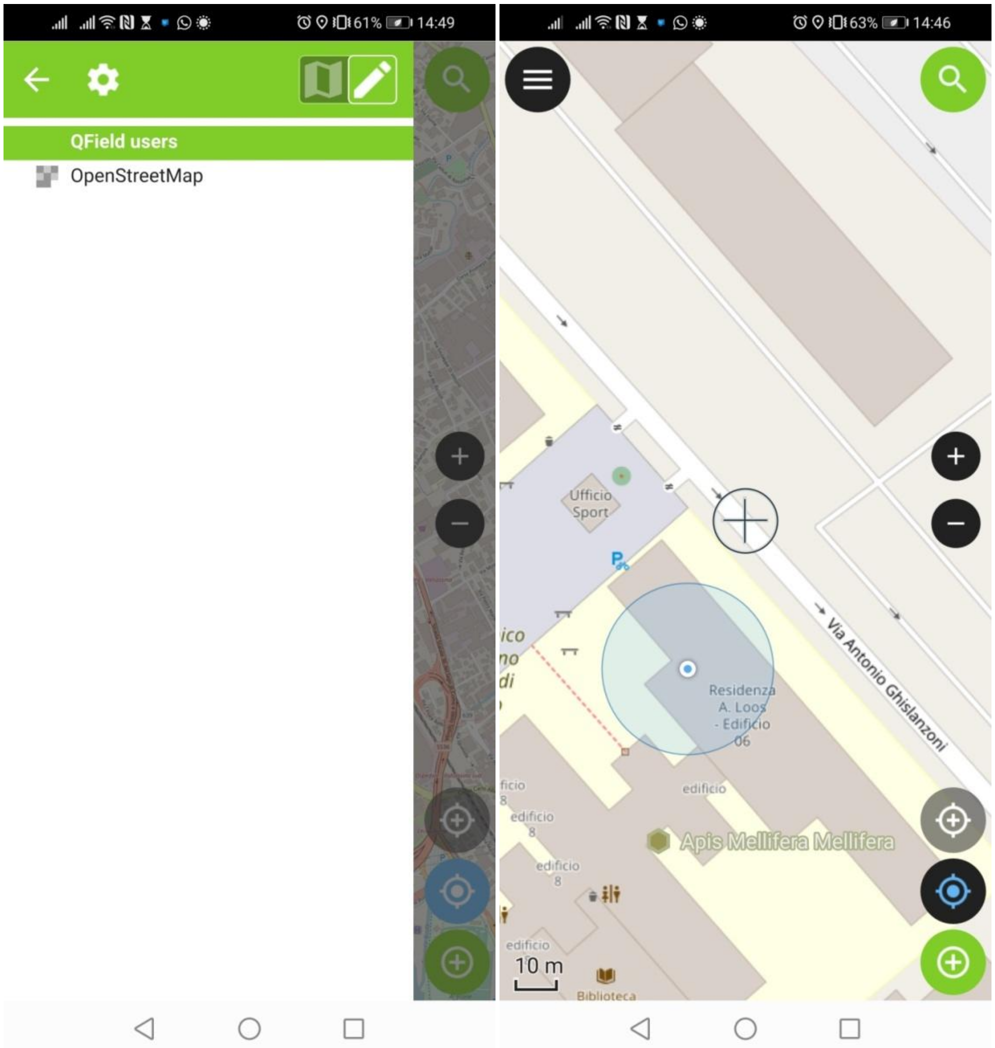

Figure 51: Screenshots of an example of point mapping in QField (1/2).

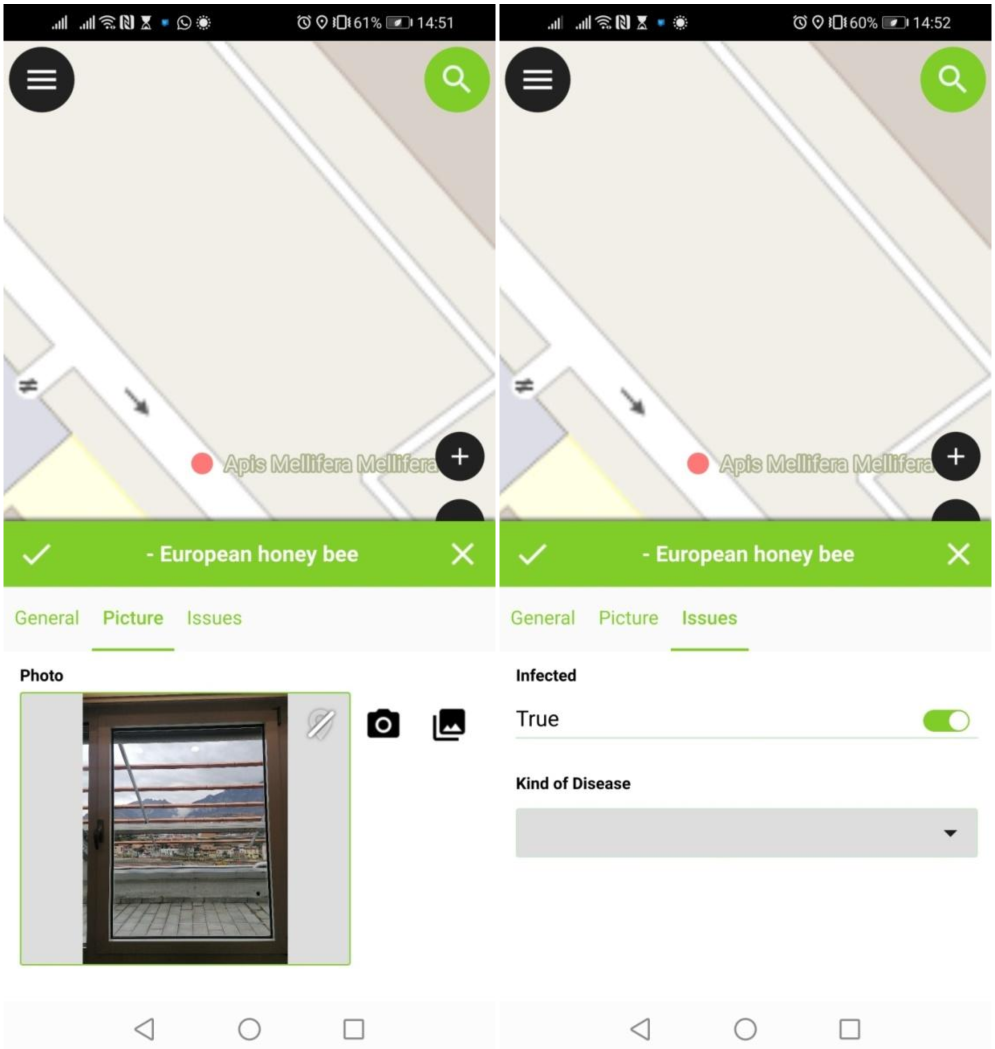

Figure 52: Screenshots of an example of point mapping in QField (2/2).

Figure 53 shows instead the procedure required by mapitGIS for the same purpose (in this case, the default project was referred to local vegetation mapping); as it can be noticed, although the graphics seems coarser with respect to the other, in this case it will be sufficient to select the mapping icon and immediately the software will provide the possibility of taking a photo. Once the image is acquired, the attribute scheme will pop-up, consenting the insertion of the needed details. Furthermore, it should be specified that if the users want to select a point that is different from their position, they can access this functionality simply by tapping on the viewfinder icon.

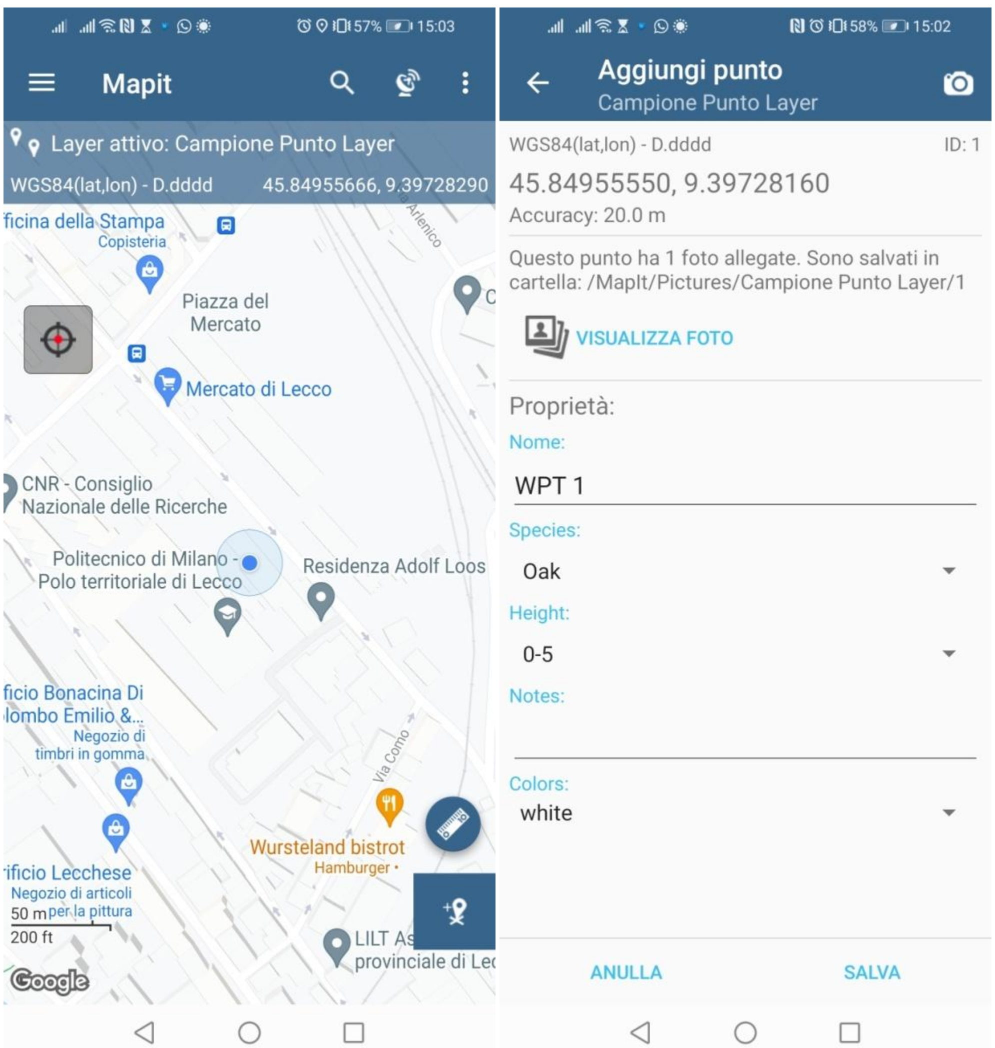

Figure 53: Screenshots of an example of point mapping in mapitGIS.

Aiming to carry on the comparisons among the two platforms, it can be of interest to state that QField is an open application (based on QGIS), meaning that its source code can be accessed and that there is an important community-based support system that contains useful documents for its employment, among which some reports of reference study cases (OPENGIS, 2021). On the other hand, mapitGIS is a private application, available for free in a basic version, whose functionalities can be expanded by paying a fee.

Lastly, another aspect to be considered is the actual possibility of using the apps for a real-time and crowd-sourcing employment; as a matter of fact, at the present time QField is not provided with a functioning teamwork functionality, that is in fact in development through a second platform named QFieldCloud (OPENGIS.ch, 2021), devoted to the specific integration of contributions coming from different people in field surveys, available online and offline and cloud-based (Beta testing is ongoing while the author is writing).

mapitGIS can be considered instead a more stable platform, already optimized for the field teamwork, with some specific functions that may improve the efficiency of procedures, such as the possibility of setting pre-filled metadata scheme if an user requires to map several times the same kind of data (e.g. a technician who is repeating the same test in different locations of a site), the fact that different kind of data are allowed as input (e.g. .txt files) or the possibility of building complete forms that should help field surveyors in organizing data. The latter function could theoretically be particularly fitting in the current project, and in case of a future development it would also be possible to translate the mentioned Fast damage reconnaissance form for dams inspection within this environment. As far as data sharing, a further comment on mapitGIS is necessary, because it is suitable to be used both for local or remote export of surveys outcomes and most of all its structure is already predisposed to be integrated within a WMS environment. Lastly, in mapitGIS website a series of user experiences describing real applications of the system can be retrieved (mapitGIS, 2021).

9.5 Critical observations on proposed expansion feasibility

Before gathering all the information presented until this point in some conclusive comments, it is needed to specify once more that this whole analysis was performed considering a further development of the project platform, without deep investigations on the different treated aspects and taking the two mentioned applications as an example of suitable environment, not aiming to have an exhaustive discussion of all the possibilities that could actually be integrated in the considered field of work.

Anyway, some considerations can be expressed; first of all, the idea of expanding the project system seems to be realistic and plausibly the use of an external app analogous to the presented one may represent an evolution for the project itself and, going further, an improvement in the described emergency management workflow.

As far as the elicitation of platform is regarded, the two analyzed alternatives are on a similar level of applicability, even though mapitGIS seems to be more suitable for professional users as well as more user-friendly in the context of photo acquisition. On its side, QField represents a free app and it is part of a constantly updating and evolving system, expressing at its best the capabilities of an opensource software.

Considering also the possibility of the future integration of QFieldCloud functionalities, the author's believe is that a deeper and more accurate analysis of the platforms would be needed at the moment of a possible implementation of the whole project system, with particular attention to the updates that in the meanwhile will be carried out by the applications developers.

10. Conclusions

In the presented work, three main outcomes were achieved, all of them related to the concept of providing innovative tools to support Civil Protection dam crisis management in seismic emergency procedures. Firstly, a WebGIS application was designed and a prototype built in the study-case of Ponte Cola dam, then an interactive form for damage reconnaissance was developed and lastly an auxiliary application to enhance crowd-sourcing upload of data was hypothesized and discussed.

With respect to the state of the art presented in chapter 2, it is possible to observe that an actual integration of the developed project may result in a concrete possibility of improving the quality and the efficiency of crisis management. This can be seen as true from different points of view, starting from the clear usefulness of the platform as a base for decision makers and operators directly involved in the deployment of emergency procedures, e.g. in control centers, considering them at all different governance levels shown in the text.

It is then possible to re-state the potential of the Fast form for damage reconnaissance, presented in section 8.5, related to the increase of efficiency in information flow among the surveyors and the stakeholders responsible for the alert phases activation. It is still relevant to underline that both the Form and the WebGIS platform itself are strictly related to the concept of saving time in emergency operations without losing quality in interventions, a crucial point that would consent to increase the efficiency and, as a consequence, save more people.

Furthermore, another relevant comment can be directed to the population involvement through the platform that if sufficiently refined and detailed could actually have strong positive influences on the management of the crisis; citizens involvement is indeed an aspect that often is not taken into consideration when addressing an emergency situation, while it has a big impact on the outcomes. A wrong behavior of the population can create several issues even hampering the field teams and their rescue operations; on the other hand, a fruitful involvement would create a coordinate action capable of boosting Civil Protection potential, thanks to the people knowledge on their own territory, with the result of improving furtherly the operations. On this side the possibility of implementing the secondary application presented in chapter 9 would allow to increase evidently the cooperative aspect, but as mentioned a spread educational campaign would be needed in order to exploit this system at its maximum.

Anyway, it is of interest also to state the limitations of the project; the main aspect to be faced in this context is the obvious dependence of intervention procedures on data quality; indeed the whole project is based on the supposed correctness and completeness of datasets made available through the platform, that would be essential to let the users employ them in a fruitful way. Data should also be updated and, in this case, the source of new information should be carefully selected, in order to be absolutely certain of its reliability (a partial solution to this aspect can be retrieved in the proposed framework for data collection shown in paragraph 9.3). Furthermore, it should be pointed out that the environment in which the prototype was built, GeoNode, presents some limitations in terms of geospatial analyses, especially for non-expert users, because for performing complex processes the knowledge of Python coding language in GIS is required or, alternatively, the use of the platform should be complemented with a Desktop application, as suggested. All in all, it is possible to consider the project platform as a tool that, with the required additional developments, could be actually published and employed in emergency management framework; in this regard it is important to state that the high level of customizability of the system could also permit the development of analogous platforms devoted to emergencies different from the analyzed one, with a relatively low computational effort.

Moving a step further and trying to imagine the project platform inclusion in the Italian Civil Protection context, it would also be possible to employ it as a unique system spread among the different regions, capable of giving information and results not only on a local scale, but on the entire national territory. At this point the system could be used as base for developing scenarios to be employed for Civil Protection training, as an example, but also as a support tool for writing new guidelines. Clearly, in this hypothesis, each region should be capable of providing their own datasets to the platform developers, a fact that will lead to much more detailed information and, most of all, once the system would be proved as useful for their own sakes, region themselves would take the role of data-updater, guaranteeing in this way contents reliability.

The last observation can be devoted to the fact that the progressive diffusion of technological instruments like the proposed one may contribute to increase awareness on their potential, being applied in different fields of work. Once their validity will be commonly recognized, it would be possible to include the employment of these platforms also in official plans, in order to constitute a new and more efficient framework for facing emergencies, in a shared and cooperative environment among regions and stakeholders, consistently devoted to ensure population safety.

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