3D Geospatial Data Management Architecture for Common Operational Picture Functionalities in Emergency Response

Iñaki Cejudo[a], Eider Irigoyen[b], Harbil Arregui[c] and Estíbaliz Loyo[d]
Intelligent Systems for Mobility and Logistics, Vicomtech Foundation, Basque Research and Technology Alliance (BRTA), Mikeletegi 57, Donostia, Spain

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Abstract: In disaster management, the emergency response commanded from the Command and Control center can make the difference for a faster and safer outcome. Novel sensing tools provide new capabilities to monitor and evaluate what happens in real time with location information of first responders and casualties being a key resource. Therefore, Geographical Information Systems (GIS) are essential when representing the Common Operational Picture to have a complete understanding of the situation in the field, obtained through big amounts of real-time data coming from multiple sources, and therefore support decision making. Moreover, the 3-dimensional representation of the terrain and buildings enhance the classical 2D map representation. In this work, a detailed overview of the architecture components and functionalities developed for a data-driven emergency response 3D web GIS application is described. In addition, a quantitative evaluation of how the number of location records collected from various numbers of first responders impacts the performance of some geospatial tasks needed for an efficient visual representation is provided, depending on the data measurement frequency.

1 INTRODUCTION

Common Operational Picture (COP) and Situational Awareness (SA) are key capabilities in disaster and emergency management. The first one, COP, consists of a unique display of the operational data, to tackle the perceived ambiguity and enable a shared overview of the crisis and the progress of the response operation to be developed (Treurniet and Wolbers, 2021). The operational data my consist of hazards, resources, means, actions, and incidents (Jagusiak and Pokorski, 2022). The second one, SA, stands for the perception of the elements of the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (Endsley, 2021).

The use of maps is one extended way of representing the COP of an emergency management as it evolves. In this sense, the transition from 2D to 3D maps is a significant improvement that helps first responders (FR) to understand the emergency environment from an additional perspective with details such as terrain slopes or building structures.

Moreover, new advances in the technology for civil protection, law enforcement, fire services, search and rescue or medical team members open a wide range of sensing capabilities and data sources that are worth being represented and exploited, for a safer and more efficient response. For instance, there is a progressive increase in the technological offer of tools that provide real-time indoor and outdoor geolocation capabilities. Taking advantage of these tools opens challenges when handling big amounts of heterogeneous positioning records, that need to be efficiently processed, stored, represented and exploited.

The present paper aims to describe the architecture and technology stack chosen to create a 2D/3D geospatial data management solution providing a set of key functionalities in a Command and Control centre during emergency response. The solution can be easily installed in a cloud server or in a dedicated computer on-premises. Then, a small comparison is given to assess how the number of location records collected from various numbers of first responders depending on its frequency can impact the response time when performing some computation tasks.

[a] https://orcid.org/0000-0002-7325-9350
[b] https://orcid.org/0000-0001-9486-0906
[c] https://orcid.org/0000-0002-7934-9250
[d] https://orcid.org/0000-0001-8232-2828

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2 LITERATURE REVIEW

In disaster management, first responders with very different roles and backgrounds participate and the heterogeneous information received in real time must be shown in an understandable way for better decision making. There are many use cases where Geographical Information Systems (GIS) technology can be of great help in multiple ways (Abdalla, 2016): Earthquakes and humanitarian coordination (the use of cutting edge GIS calculations to take care of an outline issue), wild fire (can be useful in identifying high-hazard regions within given vicinity and restrict the fire spread and thus minimize the impact), dust storms (to give the accompanying capacities in managing dust storms disaster management), health hazards (is capable in extreme heat attacks, by providing the degree and application for spatially analyzing the distribution of services and its relation to the population at risk), terrorism (capacity of using progressing 3D GIS for the headway and execution of GIS-based intelligent emergency response systems). Spatial analysis provides effective tools for managing risk and solving the mapping and assessment of hazards. It is also interesting in that it provides visual models that help decision-makers make the best use of these advancements.

The study of natural dangers and disasters in three dimensions has grown significantly during the past few years, because the interest and preference of end users towards 3D is high. Some authors argue that 3D maps have the potential to improve the disaster management process (Bandrova et al., 2012), since three-dimensional maps can resolve many perception problems and provide more clearly presented information. User interviews in that study confirmed that young people prefer 3D information. A questionnaire carried out in another study (Zlatanova, 2008), with 71 users directly involved in the emergency response (firefighters: 27, police: 11, and municipality: 33) concluded that 3D visualization was considered important by 62% of the users. This was found as a rather high result considering that half of the users were not familiar with (GIS).

Some works, nevertheless, stress that most of the conventional disaster management systems lack the support for multiple new data sources and that real-time big data processing tools that can assist decision makers with quick and accurate results (Shah et al., 2019).

In this sense, geo-spatial data or data with location component is considered as the most essential input element in latest technologies. The geo-spatial datasets need to be analyzed to gain information about disaster locations as it occurs, identify the area and people that require urgent assistance and locate appropriate areas for shelters to name the least. With the advent location-based sensors and smartphones equipped with GPS, a huge volume of geo-spatial data is generated. Spatial temporal data visualization requires powerful tools that support analysis of geospatial data over time through interactive visualization.

Enabling 3D navigation for rescuers in unknown indoor and outdoor environments, thanks to accurate 3D positioning, simplifies the logistics of emergency operations (Zlatanova et al., 2004), (Kolawole and Hunukumbure, 2022). Some works have focused on the use of images from Unmanned Aerial Vehicles (UAVs) for 3D modelling. 3D reconstruction of the scene has been proved as a crucial aspect for an efficient management of search and rescue efforts (Verykokou et al., 2018), (Mysiris et al., 2018). Exploiting different heterogeneous sources such as geolocated security cameras and their field of view has also been a topic for other research works (Hong et al., 2019). Therefore, supporting 3D maps representations in the Command and Control Centre, with real-time location information visualisation and analysis are very relevant.

However, it is difficult to exchange and incorporate 3D data sets, and make them work seamlessly with 2D spatial data resources. Therefore, the definition and use of standards is important. There are many different designers and creators of 3D standards and models. A large number of models are vendor-based, although many others are developed by international standardization organizations and come from the CAD/BIM, GIS, or Web domains. For instance, the Web Map Service (WMS) is a specification developed by the Open Geospatial Consortium (OGC), that has also become an ISO standard (Jagusiak and Pokorski, 2022), for serving georeferenced map images over the Internet. These images are typically produced by a map server from data provided by a GIS database. At the same time, 3D Tiles is another OGC open standard for massive heterogeneous 3D geospatial datasets such as point clouds, buildings, photogrammetry, and vector data.

Some well-known software solutions implement these and other standards. For instance, Geoserver (Iacovella, 2017), an open source map server for sharing geospatial data used in some emergency management applications (such as (Li et al., 2015)), implements WMS, Web Feature Service (WFS) Web Coverage Service (WCS), and additional protocols like Web Processing Service (WPS) through available extensions. CesiumJS (https://cesium.com/platform/cesiumjs/), is an open platform that implements 3D Tiles and uses the map engine of WebGL to provide multi-dimensional earth and real terrain display. Some recent works have used this platform for representing virtual situations for urban road emergency training (Gao et al., 2022). However, for the authors knowledge, no other works have presented a platform architecture to be used during emergency response, ready for being integrated with additional data sources in real time.

3 ARCHITECTURE

3.1 Architecture and Components

The solution is formed mainly of a CC web application, a set of databases, a map serving tool and an API server that hosts the business logic offering the functionalities on top of the emergency database to the web application (Fig. 1). In addition, a set of auxiliary tools and components support other tasks such as the user authentication and the interaction with external data sources. The proposed solution also includes two client applications relying on augmented reality to offer the first responders deployed in the field an enhanced understanding of their surrounding (for smartphone and smart see-through glasses).

3.1.1 CC Web App Interface

The proposed solution is a web-based Command and Control application with geospatial visualization and geocomputation capabilities. Its main objectives are the representation of the area of the scenario and a real-time visualization of the spatial types of data of elements (FR, sensors, geolocated elements...) that are taking part. Data is obtained from third party tools that are able to monitor different elements while running an emergency planning/operation. The application includes user management capabilities and emergency inventory management. The frameworks used to build the application are:

- JHipster (Raible, 2016): Open source development platform to generate, develop and deploy web applications and microservices.
- CesiumJS: Open source javascript library for creating 3D globes and maps. Its main strength is the 3D geospatial visualization.

3.1.2 Geoserver

Geoserver (Iacovella, 2017) is a well-known open source server for sharing geospatial data. It also has geocomputation capabilities. It implements OGC protocols such as Web Feature Service (WFS), Web Map Service (WMS) or Web Processing Service (WPS). Geoserver serves as a map serving tool for the web based application. Contents have been added from OpenStreetMap (Bennet, 2010). Apart from serving the base map layer to the web application, Geoserver is also used for heatmaps representation and emergency centroid calculation. This centroid is calculated based on all the elements associated to an emergency and is used to center the map when visualising to the command and control operator user.

3.1.3 Relational Databases

The architecture involves one main relational database (Emergency database) persisting the real-time and historical information of the evolution of the disaster response. Other databases are used for user authentication and for the storage of map base layers information. Postgres (Momjian, 2001) was selected for these databases, with the PostGIS extension (not needed for the authentication database).

3.1.4 API Server

The main business logic of the emergency management is provided by an API server consisting of a set of REST API methods, working on top of the Emergency database, developed in Java Spring Boot (Walls, 2016).

3.1.5 Smartphone/Smart Glasses Augmented Reality Client Applications

The CC WebApp interface is complemented with two client application versions for the first responders deployed in the field. They use augmented reality to represent information of the relative location and distance to other first responders, their risk situation and the relative location and distance of georreferenced elements of interest (Arregui et al., 2022).

3.2 Interfaces and Input Data from Other Tools

Data from different sources are received from a middleware system, also developed in the research project but out of the scope of this paper. This system is in charge of the management and fusion of multiple data sources such as sensor information from wearables or drones. It is a bundle of software services with functionalities for data source management and secure data flow among others. The API service developed includes a specific endpoint for each data source

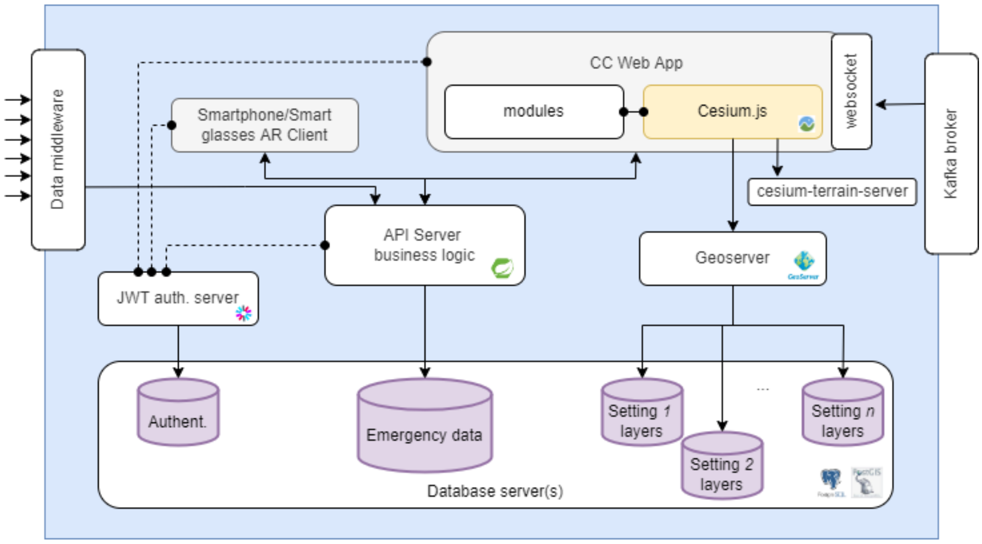

Figure 1: Architecture diagram of the technology stack.

and acts as a consumer of this middleware, so that the received information can be exploited and persisted in a structured manner.

Apart from this middleware system, a Kafka broker for asynchronous messaging has also been included. This broker interacts with a websocket used by the CC WebApp to represent received alerts in real-time in the web user interface.

4 MAIN FUNCTIONALITIES PROVIDED

After describing the main components in the previous section, the main functionalities that the CC solution provides are described in the following.

4.1 User Management

The concept of user management describes the ability of administrators to manage and configure user access to different IT resources such as services, applications or systems. It is a key concept that enables security and controls who is able to access what information or service. A CC application requires a secure access to handle and interact with all the information and functionalities. This access is granted by the use of user-based authentication.

4.2 Scenario Management

The same Command and Control application hosted in a server or an on-premise deployment can be used, in general, to operate in different emergencies and geographical areas. This can occur in different time frames or simultaneously. Therefore, having ways to separate the scenarios is a useful capability. The management of the emergency scenario involves multiple stages in order to setup all the configuration and device resources that need to be associated to the corresponding first responders.

- Creation of a new setting. The concept of "setting" stands for an area where many emergencies can be added. A setting can be, for instance, a country, a state or a city.
- Creation of a new first responder
- Creation of a new emergency. Location, start date and first responders can be specified among other fields.
- Edition of an emergency
- Save a new device
- User configuration where an application user can be assigned to a first responder.
- Adding or removing associations between first responders and devices they may carry or wear.

The creation of a new setting is enabled if separate geographical areas are expected to be covered by a unique deployment of the CC application. This enables the association of each geographical area with the available maps.

Inside a setting, multiple emergencies can be covered simultaneously. Each emergency is focused on a more specific geographical area specified by the limits of a bounding box. Running emergencies are marked as "active" but finished ones and the associated information recorded are persisted for future

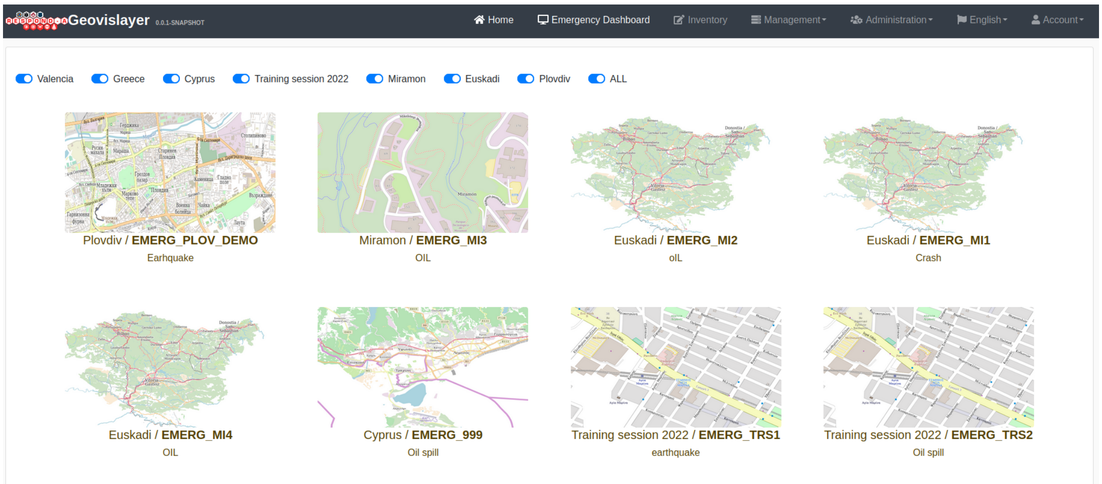

Figure 2: Emergency Dashboard to select an emergency.

post-emergency studies. The Emergency Dashboard, Fig. 2, visualizes a screenshot and basic information of all the created emergencies, and they can be filtered by Scenarios. When any of these emergencies is selected, the application enters in 3D map visualization view.

In each emergency, a list of first responders is assigned.

4.3 Resource and Device Configuration

Multiple and heterogeneous types of resources are usually used in an emergency operation. For instance, first responders are personal resources. Other types of resources can be vehicles, tools, machinery, sensors or other equipment. Sometimes these resources need to be associated to a given first responder. For instance, the information coming from a wearable sensor must be linked to a specific first responder.

Many of the tools developed in the current research project are resources that provide different kinds of data, shared through a common data middleware. This information is represented in the CC application if the correct IDs are associated to the first responder, for instance if the sensor is providing the health status or positioning of the first responder. However, not all devices need always to be attached to a first responder. We address the following resources or devices providing data: a) Video sources: streaming video from sources like thermal cameras will need to be configured in order to have access to their incoming contents; b) Drones; c) Wearables.

This association between a first responder and a device needs to be done by emergency, since from one emergency to another the personal resources and the devices they will be using could rotate.

4.4 Layered 2D, 3D Maps and Road Network Information

Geospatial base layers are key to represent the geographical context where the emergency operation occurs. In summary, a map layer is a GIS component containing groups of points, lines or polygon features that represent real-world entities, or images (like satellite imagery). They help locating what is happening, and where the personnel and technical resources are in relation to other points of interest.

These kinds of layers are provided through Geoserver, the selected open source standalone GIS server which provides the main OCG capabilities to work with 2D spatial tiles in an interoperable way, on top of a PostGIS relational database server.

To construct the 2D maps, contents have been downloaded from OpenStreetMap, and prepared to be served through Geoserver in form of tiles. The road network information is also extracted from OpenStreetMap and incorporated to the PostGIS database so that Geoserver can also serve it. To visualise a 3D Terrain, a DEM (Digital Elevation Model) of the area to be represented is required. For instance, a digital elevation model of Cyprus has been used (Paraskeva, 2016). This file is processed in order to create tiles and these are served using the OGC standard Web Map Service (WMS).

Cesium (the underlying library of the CC application) accepts heightmap or quantized-mesh type tiles. The latter is more optimised for rendering. To process and create the tiles the *cesium-terrain-builder-docker* (https://github.com/tum-gis/cesium-terrain-builder-docker) utility is used. Afterwards, in order to serve the tiles, the *cesium-terrain-server* (https://github.com/geo-data/cesium-terrain-server) utility is used. The *CesiumTerrainProvider* component will then be able to load the terrain from the URL provided by the *cesium-terrain-server* server, Fig. 3.

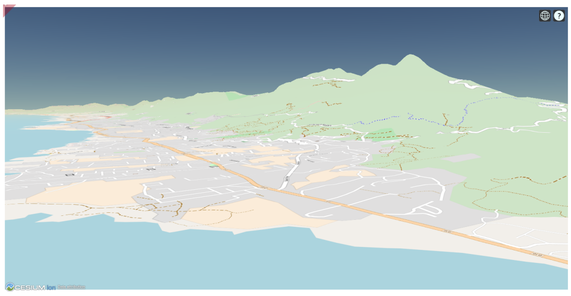

Figure 3: Representation of 3D terrain elevation.

4.4.1 Offline Mode

2D and 3D layers can usually be obtained through third party map service providers, and this is a very usual approach in software applications using maps. But this requires a constant connection to their remote servers. It is quite usual that during an emergency, the access to internet is limited or completely lost. And only a private local network is available to ensure communication among first responders and the emergency management tools. Using self-hosted services such as Geoserver instead of relying on external map providers, the lack of internet connection during the critical situation does not restrict the map usage.

4.5 First Responder Localisation and Tracking

This capability enables displaying the position of a first responder over a digital map and see their positions change over time. It is key to ensure the Command and Control operators know where first responders in the field are, with an acceptable delay and an acceptable precision in space. The accuracy of the positioning will strongly depend on the device providing that data, but the Command and Control application will need ensure that it is represented using the correct spatial referencing system. The information of all the geolocated first responders is shown on 2D or 3D maps according to their real-time location, following stablished refresh-rates, which can be fixed or personalised by each user.

Capabilities for outdoor and indoor localisation are provided by the CC application, for instance, enabling 3D representations of buildings and the location of the first responders at different levels. CesiumJS includes the possibility of representing polygons. For indoor locations of first responders or casualties, buildings can be represented as simple extruded polygons or as specific 3D models created on purpose. Fig. 4 is a 3D model example of a building.

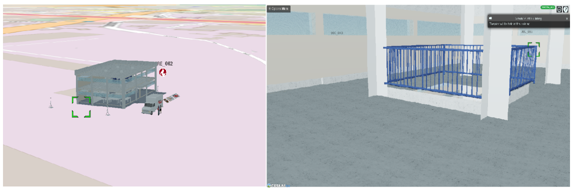

Figure 4: 3D building for indoor representation.

4.6 Route Calculation

Route calculation is a functionality that helps obtaining an optimal path to reach a final objective position from a given initial position. This optimal path is usually computed as the path that implies the lowest cost. The most common ways of quantifying this cost are distance and travel time. Multiple well-known algorithms exist to obtain optimal or near-optimal results (sometimes a compromise must be found, because the computation time to get the best result might be excessive). In general, the input for these algorithms is a set of ways and nodes, modelled as a graph. Having the road network imported as a graph is of high importance in order to be able to compute shortest paths by using algorithms like Dijkstra (Dijkstra, 1959) and A* (Hart et al., 1968). The CC application enables the calculation of the shortest path between two locations. Currently, the changes of the road network due to an incident are not supported but this is a functionality envisioned for the future roadmap of the tool. After requesting a route between two first responders, the computed path is printed in the map, and distance and duration information are displayed as shown in Fig. 5.

4.7 Cataloguing and Location of Necessary Equipment and Geospatial Elements

The CC application supports the creation of geospatial elements of interest by drawing them on a map. These can be generic "POINT", "LINE" or "POLYGON" shape types of elements. This allows displaying them on the map in client applications carried by first responders in the field. For instance, the Inventory creation functionality provided by the CC application acts as an authoring tool that creates geospatial entities that are then displayed within the asigned emergency, and can be used by any other application that uses the API, such as the augmented reality

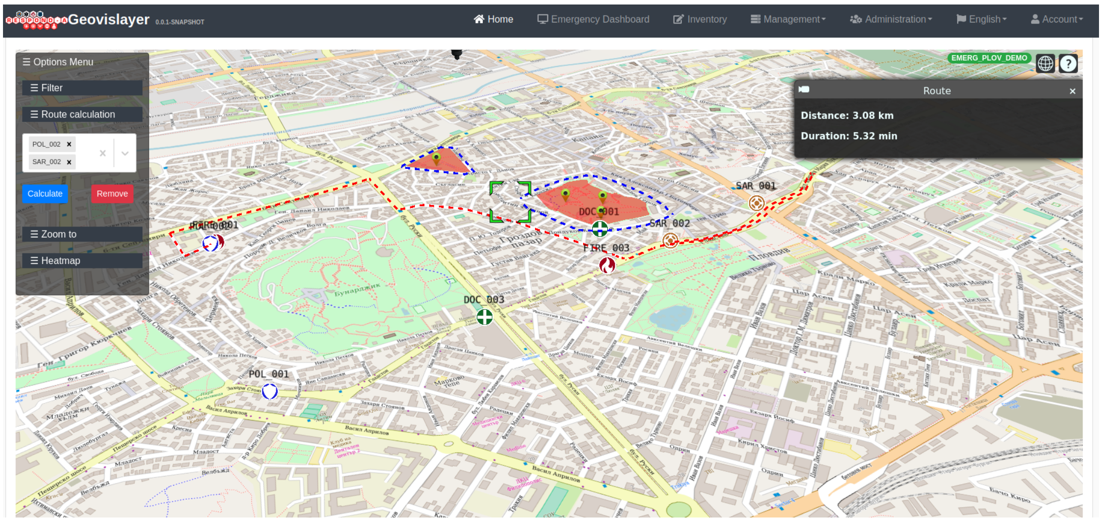

Figure 5: Visualisation of the route path with associated details (distance and duration).

smartphone and see-through glasses clients. In addition to the shape type, currently, the elements can be categorised into Resources, Citizens in Risk, Danger Area, Alerts or Mobile Command and Control Centre location. The user is able to draw the element on the map and it is then saved in the system with associated details.

4.8 Real-Time Environmental and First Responders Health Status Through Sensor Data Visualisation

Via third party tools, the data collected by multiple wearable sensors and centralised by the data logger are shared through the middleware system. This information gives valuable insights of the situation of the first responders' safety, apart from the localization data that has previously been addressed. In addition, it enables quickly alerting the commanders to a potentially injured FR and it provides actionable intelligence without needing audio or visual communication between the FR and their commander.

4.9 Drone Flight Plan and Telemetry Visualisation

Drones are another key part of emergency management. They are very valuable resources that help operations from an aerial perspective. Integrating their information in Command and Control applications is very useful. Via the middleware system, telemetry information of the drones are shared with the Command and Control application in order to display their status and position in real time. For instance, the CC application is capable of displaying and updating the position with a given refresh rate. The main purpose of this functionality is not handling the flight mission, which needs a very frequent and critical monitoring to guarantee the safety of the UAV and the personnel involved but following their approximate situation in context with the rest of the elements and resources being part of the emergency operation. In Fig. 6, the position and details of a flying drone are represented on the map. Since the CC application allows 3D visualization of the scene, apart from the 2D positions, the elevation can be represented. Moreover, showing or hiding the expected flight plan is enabled.

4.10 Alerts

The management of alerts is key to allow acting fast and efficiently in decision-making. This is valid for first responders in the Command and Control Centre and for the ones deployed in the field. Displaying alerts that require attention from a responsible at the Command and Control Centre is an important functionality. In general, alerts are expected to be shared through the middleware system. In addition, a specific component enables subscription to Common Alerting Protocol servers provided by authorized entities.

4.11 Post-Emergency Functionalities

The post-emergency management of the collected information helps to understand and evaluate the emergency response, once finished. The following functionalities are given:

- Statistics dashboards: Interactive charts and tables

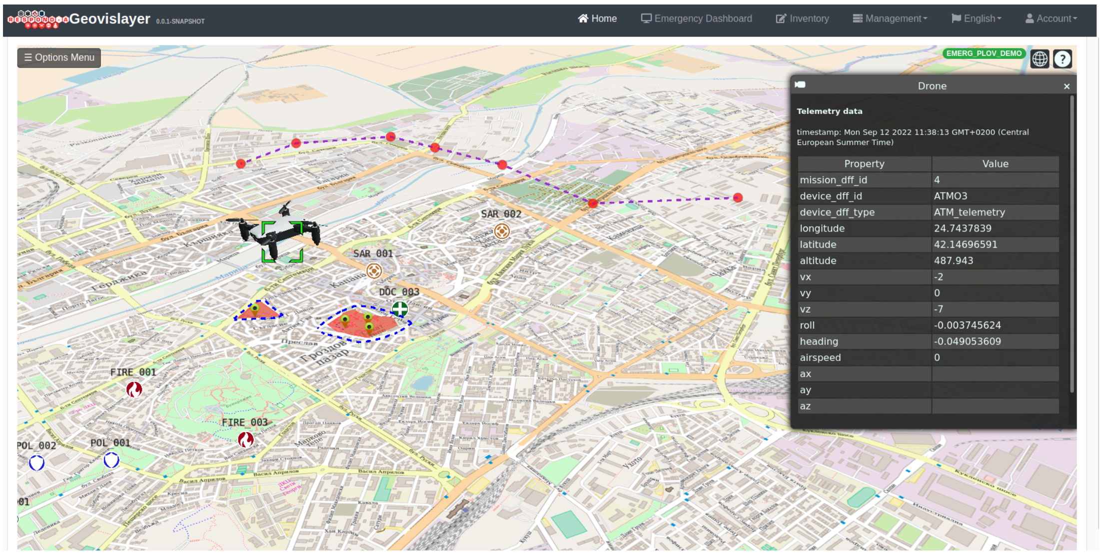

Figure 6: Flying drone details with activated visualisation of the flight plan.

about statistics of alarms, numbers of exchanged messages, number of injured people treated.

- Reporting: Creation of summary reports about the evolution of the emergency from the beginning to the end.
- Geospatial statistics: This helps understanding the movements of first responders in the field, extracting quantitative data about areas visited, distances they have traveled, time to reach some locations, time they have spent in a dangerous zone, and so on. Visual representations such as charts and heatmaps are used (Fig. 7).

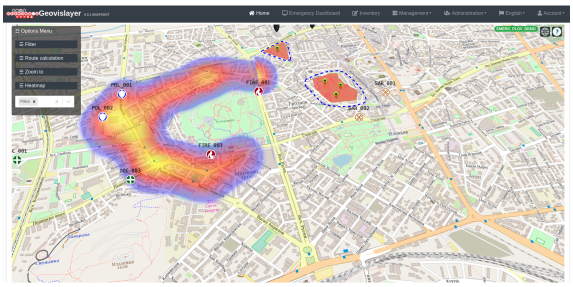

Figure 7: Heatmap with positions from a filtered first responder.

5 DESCRIPTION OF SPATIAL DATA MANAGEMENT MODULES

5.1 Web Interface Folder Structure and Components

Folder structure of the project consist on several folders with functional components in them. Main folder is “modules” folder. This is where most of the web application functionalities reside. Inside this folder, we have:

- “account” folder: Components for account management functionalities.
- “administration” folder: Components web administration functionalities.
- “login” folder: Components for login/logout functionalities.

Most of the visual components of the web application are in the following folders:

- “emergencies” folder: Component that show the emergency dashboard.
- “inventory” folder: Components for creating new shapes in the emergency.
- “map” folder: Components for the main 3D geospatial visualization of an emergency.

5.2 Cesium as the Core GIS Component

The main web interface component is where the emergency map and information are embedded in the website, using CesiumJS, an open source javascript library for creating 3D globes and maps.

When an emergency is selected in the emergency dashboard, this component automatically loads. Cesium's *WebMapServiceImageryProvider* function loads a base map for the world globe and a detailed map of the emergency setting from Geoserver. In the process of loading the component, there are several API calls to retrieve emergency information. There are three types of calls:

- API calls made only once, when the component loads:
  - */generalTypes/list*: Returns a list of all types (FR + shapes) in the emergency.
  - */settings/getSettingById?settingId*: Returns setting basic information.
  - */GeoJson/minimumBboxByEmergency? emergencyId*: Returns the minimum bounding rectangle of last positions of FRs and shapes of interest.
- API calls made when the component loads and also every time information is updated:
  - */firstResponders/lastPosition?emergencyId*: Returns a list of FRs and its positions in the emergency.
  - */GeoJson/lastPositionByEmergency? emergencyId*: Returns a list of shapes of interest and its positions in the emergency.
  - */deviceInfo/getLastTelemetriesByEmergencyId? emergencyId*: Returns a list of drones and its data in the emergency.
- API calls made when the operator selects a specific entity (first responder or drone):
  - */deviceInfo/getLastDataEnvironmentById? responderId*: Returns environment data provided by the device the selected FR is wearing or carrying.
  - */deviceInfo/getLastVitalSignsById?responderId*: Returns health data provided by the device the selected FR is wearing.
  - */deviceInfo/getMissionByDeviceId?deviceId*: Returns mission information of the selected drone.

5.2.1 Initial Flight to the Emergency Location

When the main component has loaded and the initial information has been retrieved from the API, the first operation that is done is an initial camera flight to the center of the bounding rectangle of the emergency. For this operation, Cesium's *CameraFlyTo* function is used and the coordinates are obtained from */GeoJson/minimumBboxByEmergency?emergencyId* API call.

5.2.2 Information Visualization

The World globe, map layers and emergency entities are visualized using Cesium's Viewer component. Any Cesium function has to be inside this component. Cesium has different kind of components for visualizing Entities. The ones used in this application are the following:

- *ModelGraphics:* loads 3D models in glTF format (drones, buildings, ...).
- *PolylineGraphics:* used for representing drone flight plan, line shape of interest, and route information.
- *BillboardGraphics:* loads an image representing a first responder type or any other point as a shape of interest.
- *LabelGraphics:* used for showing a first responder's code.
- *PolygonGraphics:* used for showing polygon shape of interest.
- *PointGraphics:* used for representing drone's mission waypoints.

5.2.3 3 D Terrain

With Cesium, apart from imagery layers, specific terrain layer can be imported. In our case, we import 3D terrain using *CesiumTerrainProvider* function.

- From a DEM (Digital Elevation Model), tiles in quantized-mesh format are created with open source project: *cesium-terrain-builder-docker*.
- The 3D terrain is hosted in an open source server: *cesium-terrain-server*.

5.2.4 Heatmap

Using *WebMapServiceImageryProvider* too, a heatmap layer of positions of first responders can be represented. This layer is created in Geoserver applying a transformation to a style.

5.2.5 User Interaction

User can move the view in any direction and can select any entity displayed in the viewer. When an entity is selected, a description is shown with *EntityDescription* component.

There is also a menu function called "Zoom to" where user can redirect the camera to any first responder or shape of interest in the emergency. Cesium's *CameraFlyTo* function is used, as for the initial camera position.

There is an specific component for creation of new shapes in the emergency. Cesium viewer's 3D globe is loaded, an the user can select what emergency wants to work on. The user can manually draw point, line or polygon shapes in any place of the map, assign a category to the shape and save it. Cesium has a *ScreenSpaceEventHandler* function for managing user clicks over the Cesium Viewer. Once the new shapes are saved, they are included in the Emergency Database and can be visualized using the CC application or any other application that uses the API.

5.3 Geoserver Map Creation Process

The process for serving a map with Geoserver starts obtaning an OpenStreetMap file of the wanted area. This map has to be processed into a PostGIS database with Imposm tool (https://imposm.org/). Applying a specific mapping in Imposm, converts the map information into several database tables. Then, Geoserver allows to import these tables. Each one works as a layer in Geoserver. For visualizing a layer like a typical map, an specific style has to be applied to each layer. For the creation of the whole map, we are not using all the layers, just a custom selection of them. The desired layers must be grouped into a "layer group". The order in which the layers are added when creating this group is important.

Once the map is created, it is served to the CC application by WMS (Web Map Service) standard.

6 PERFORMANCE EVALUATION

The performance of the multiple tasks and functionalities is affected by the database size. Therefore, research to evaluate how this size would affect the interaction of the user with the application is needed.

For instance, one of the features of the CC application is the initial flight described in section 5.2.1. To calculate the bounding rectangle of the last positions received of first responders in an emergency, the */GeoJson/minimumBboxByEmergency?emergencyId* API call has been implemented using PostGIS. Another way to calculate the bounding rectangle is to make use of WPS functions implemented in Geoserver. In order to know what is the more efficient way to perform the calculation a time comparison has been made.

The main factor for the time comparison is the number of registers saved in the database, because of this, different scenarios have been defined. In Table 1, the first column specifies the frequency with which a record is received, the second column defines the duration in which the data is received and the third one, the total number of records received for each FR in that scenario. For example, the first row specifies that 1 record is received every 300 seconds during 3 hours. Each scenario has been tested with a different number of first responders (1, 5, 15 and 25).

The data obtained (Table 2) show that the response time increases exponentially from 300 records per FR in the case of the api (Fig. 8) and from 540 records per FR in the case of Geoserver (Fig. 9).

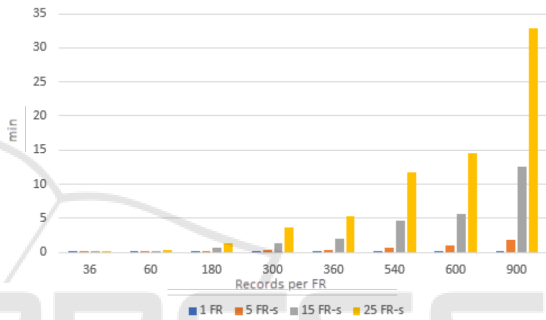

Figure 8: API response time comparison.

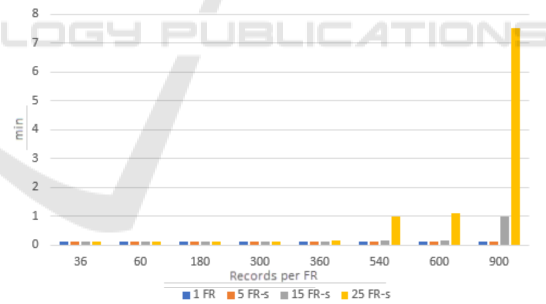

Figure 9: Geoserver response time comparison.

Focusing on scenarios with more records (Fig. 10), the response of the API, in the worst case, is 2746% slower than Geoserver's (the case of 1 record every minute during 5 hours with 25 first responders). Therefore, as future work, it is necessary to improve the implementation of the API to make it scalable.

Table 1: Definition of number of records per FR.

Time Period (s)	Duration (h)	Total records (per FR)
300	3	36
300	5	60
60	3	180
60	5	300
30	3	360
30	5	600
20	3	540
20	5	900

Table 2: API and Geoserver (GEO) response times in seconds, according to records per FR.

FRs	Method	36	60	180	300	360	540	600	900
1	API	0.08	0.10	0.10	0.12	0.12	0.13	0.15	0.25
	GEO	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11
5	API	0.10	0.12	0.20	0.30	0.39	0.70	0.92	1.90
	GEO	0.10	0.10	0.11	0.11	0.10	0.12	0.12	0.13
15	API	0.13	0.15	0.60	1.40	2.00	4.60	5.70	12.60
	GEO	0.11	0.11	0.12	0.13	0.10	0.14	0.15	1.00
25	API	0.18	0.28	1.40	3.70	5.30	11.80	14.60	32.80
	GEO	0.11	0.12	0.12	0.13	0.20	1.00	1.10	7.50

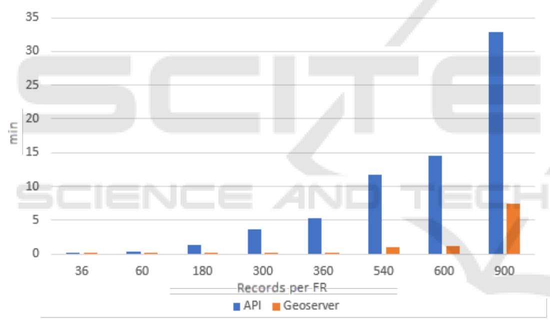

Figure 10: Comparison between API and Geoserver times for 25 first responders.

7 DISCUSSION AND FUTURE WORK

Results show the quantitative impact of the amount of records and the frequency of sensor data captured when performing some geospatial tasks needed to operate the web 3D GIS application, depending on the method used. The differences show that working on the scalability of the solution when developing custom functions is a must. To do so, the application and evaluation of geospatial stream processing frameworks is envisioned.

Moreover, expected future improvements will also cover the update of the routing network, so that shortest path algorithms are dynamically adapted to areas that need to be avoided, and extending these algorithms for evacuation means. In addition, an easier creation and adaptation of the geographical regions cartography in the application by means of semi-automatic tools is planned.

8 CONCLUSIONS

This paper has described the architecture and a software solution developed to support first responders, with a special focus given to the technology stack used for a 3D geospatial data management. The architecture is prepared to be able to interact with real-time data coming from different heterogeneous sources that support an emergency during its Response stage. Evaluations have been carried out to understand the impact that the number of first responders and the frequency of the data received have in geospatial computational tasks such as the calculation of the bounding box that contains all the spatial elements to be represented. An exponential increase of the response times is shown, with the need to address scalability approaches through geospatial stream processing frameworks. The solution has been designed to visualize and manage emergencies, aimed to be used inside an emergency command and control center. However, the developed components and the global architecture presented can be extended to be used in other different Command and Control (CC) applications beyond emergency management, where spatial capabilities can be of special help, such as smart cities and transportation and logistic sectors.

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REFERENCES

Abdalla, R. (2016). Evaluation of spatial analysis application for urban emergency management. *SpringerPlus*, 5.

Arregui, H., Irigoyen, E., Cejudo, I., Simonsen, S., Ribar, D., Kourtis, M., Spyridis, Y., Stathakarou, N., and Batistatos, M. (2022). An augmented reality framework for first responders: the respond-a project approach. pages 1–6.

Bandrova, T., Zlatanova, S., and Konečný, M. (2012). Three-dimensional maps for disaster management. volume I-4.

Bennet, J. (2010). *OpenStreetMap*. Packt Publishing Ltd.

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs. *Numerische mathematik*, 1(1):269–271.

Endsley, M. R. (2021). Situation awareness. *Handbook of human factors and ergonomics*, pages 434–455.

Gao, X., Zhang, J., Zou, R., Li, J., and Cao, Z. (2022). Multi-user collaborative virtual emergency drill system for urban road emergencies. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, X-3/W2-2022:9–15.

Hart, P., Nilsson, N., and Raphael, B. (1968). A formal basis for the heuristic determination of minimum cost paths. *IEEE Transactions on Systems Science and Cybernetics*, 4(2):100–107.

Hong, J.-H., Lu, Y.-H., and Chen, C.-H. (2019). The use of cctv in the emergency response: A 3d gis perspective. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42:19–25.

Iacovella, S. (2017). *GeoServer Beginner's Guide: Share Geospatial Data Using Open Source Standards*. Packt Publishing Ltd.

Jagusiak, B. and Pokorski, G. (2022). Application of transport security system symbology for emergency mass notification systems. *Transport Problems: an International Scientific Journal*, 17(3).

Kolawole, O. and Hunukumbure, M. (2022). A drone-based 3d localization solution for emergency services. In *ICC 2022-IEEE International Conference on Communications*, pages 1–6. IEEE.

Li, B., Wu, J., Pan, M., and Huang, J. (2015). Application of 3D WebGIS and real-time technique in earthquake information publishing and visualization. *Earthquake Science*, 28:223–231.

Momjian, B. (2001). *PostgreSQL: Introduction and Concepts*. Addison-Wesley Longman Publishing Co., Inc., USA.

Mysiris, P., Doulamis, N., Doulamis, A., Sourlas, V., and Amditis, A. (2018). Pervasive 3d reconstruction to identify hidden 3d survival spaces for search and rescue management. In *2018 IEEE 16th Intl Conf on Dependable, Autonomic and Secure Computing, 16th Intl Conf on Pervasive Intelligence and Computing, 4th Intl Conf on Big Data Intelligence and Computing and Cyber Science and Technology Congress(DASC/PiCom/DataCom/CyberSciTech)*, pages 808–813.

Paraskeva, C. (2016). A Digital Elevation Model for Cyprus based on the ALOS 2 W3D30 Digital Surface Model. https://doi.org/10.6084/m9.figshare.3159991.v1.

Raible, M. (2016). *The JHipster Mini-Book*. Lulu.com.

Shah, S. A., Seker, D. Z., Hameed, S., and Draheim, D. (2019). The rising role of big data analytics and IoT in disaster management: Recent advances, taxonomy and prospects. *IEEE Access*, 7:54595–54614.

Treurniet, W. and Wolbers, J. (2021). Codifying a crisis: Progressing from information sharing to distributed decision-making. *Journal of Contingencies and Crisis Management*, 29(1):23–35.

Verykokou, S., Ioannidis, C., Athanasiou, G., Doulamis, N., and Amditis, A. (2018). 3d reconstruction of disaster scenes for urban search and rescue. *Multimedia Tools and Applications*, 77.

Walls, C. (2016). *Spring Boot in Action*. Manning Publications Co., USA, 1st edition.

Zlatanova, S. (2008). SII for emergency response: the 3D challenges.

Zlatanova, S., Oosterom, P., and Verbree, E. (2004). 3D technology for improving disaster management: GEO-DBMS and positioning. *Proceedings of The IEEE - PIEEE*.