TEMA

TRUSTED
EXTREMELY PRECISE
MAPPING AND PREDICTION
FOR EMERGENCY
MANAGEMENT

D6.2:
Initial integrated TEMA platform for trials

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D6.2 – Initial Integrated TEMA platform for trials			
Executive Summary:	This deliverable, D6.2, presents the initial integration of the TEMA platform, showcasing its architecture, core components, and deployment in real-world pilot trials across Europe. The platform integrates over 26 independent technologies contributed by European partners, encompassing AI, remote sensing, simulation, data fusion, and geospatial visualization.		
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Author(s):	**Francesco Arigliano (ENG), Antonio Filograna (ENG)**		
Editor:	**Dmitriy Shutin (DLR-KN)**		
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Disclaimer

The TEMA consortium consists of the following partners:

No.	Partner Organisation Name	Partner Organisation Short Name	Country
1	ARISTOTELIO PANEPISTIMIO THESSALONIKIS	AUTH	GR
2	DEUTSCHES ZENTRUM FUR LUFT – UND RAUMFAHRT EV	DLR	DE
3	ENGINEERING - INGEGNERIA INFORMATICA SPA	ENG	IT
4	ATOS IT SOLUTIONS AND SERVICES IBERIA SL	ATOS IT	ES
4.1	ATOS SPAIN SA	ATOS SP	ES
5	UNIVERSIDAD DE SEVILLA	USE	ES
6	TECNOSYLVA SL	TSYL	ES
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21	INTERDISCIPLINARY TRANSFORMATION UNIVERSITY	IT:U	AT

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Authors/Contributors

Name	Partner
Francesco Arigliano, Antonio Filograna	ENG
Andreas Kramer, Ehsaneddin Jajilian	IT:U
Monika Friedemann	DLR
Fabrizia Soi, Salvatore Cinus	RAS
Leila Arras	FHHI
Joost van Dijk	NS C
Joep Grispen	NS
Eleonor Fragachan	ATOS
J. Ramiro Martinez, Abdalraheem Ijjeh	USE
Massimo Villari, Lorenzo	UNIME
Michael Siavrakas, Dimitrios-Matthaios Tzimas, Eugenios Vlachos, Zamioudis Alexandros, Evangelos Charalampakis, Dimitrios Fotiou, Ioanna Valsamara	AUTH
Juha Moilanen	KAMK

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Miguel Navarrete	TSYL
Andrea Montieri	LAT40
Margareta Mihalic Dogan	BRK

Reviewers

Name	Organisation
Dmitriy Shutin	DLR

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List of Terms and Abbreviations

Abbreviation	Description
DE	Digital Enabler
AI	Artificial Intelligence
API	Application Programming Interface
BM	Business Mission
CSV	Comma-Separated Values
DEM	Digital Elevation Model
DT	Digital Twin
GeoJSON	Geospatial JSON standard
GIR	Geospatial Information Retrieval
GPU	Graphics Processing Unit
GPKG	GeoPackage
H3	Hexagonal hierarchical geospatial index
JSON	JavaScript Object Notation
JSON-LD	JSON for Linked Data
K3s	Lightweight Kubernetes distribution
KMZ	Zipped Keyhole Markup Language
MinIO	Object Storage Server (S3 compatible)
MODIS	Moderate Resolution Imaging Spectroradiometer
NGSI-LD	Next Generation Service Interface – Linked Data
CB	Orion Context Broker
OGC	Open Geospatial Consortium
OLCI	Ocean and Land Colour Instrument (Sentinel-3)

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PNG	Portable Network Graphics
RDF	Resource Description Framework
REST	Representational State Transfer
ROS	Rate of Spread (Fire behaviour)
S3	Amazon Simple Storage Service API
SfM	Structure from Motion
SOTA	State of the Art
STAC	SpatioTemporal Asset Catalog
TIFF	Tagged Image File Format
UAV	Unmanned Aerial Vehicle
VPN	Virtual Private Network
WFS	Web Feature Service
WMS	Web Map Service
WP	Work Package
XR	Extended Reality

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Executive Summary

The TEMA project (Trusted Extremely Precise Mapping and Prediction for Emergency Management) aims to develop a robust, scalable, and interoperable platform for managing natural disasters such as floods and wildfires. This deliverable, D6.2, presents the initial integration of the TEMA platform, showcasing its architecture, core components, and deployment in real-world pilot trials across Europe.

The platform integrates over 26 independent technologies contributed by European partners, encompassing AI, remote sensing, simulation, data fusion, and geospatial visualization. To address the challenges of interoperability and scalability, TEMA adopts a microservices-based architecture coordinated via the Orion Context Broker (OCB), enabling real-time, event-driven communication and semantic interoperability through NGSI-LD standards.

The platform is structured into four layers:

- Data Layer: Aggregates heterogeneous sources including drones, satellites, sensors, and social media.
- Integration Layer: Manages data flow and orchestration via OCB and MinIO object storage.
- Processing Layer: Supports batch and near-real-time analytics using AI and simulation tools.
- Visualization Layer: Provides situational awareness through Smartdesk and XR-based interfaces.

In addition to Software Integration, the Hardware Integration between drones, meteorological stations, and edge/cloud infrastructure, essential for real-time data acquisition and processing was depicted.

The platform has been successfully deployed in multiple pilot trials, demonstrating its ability to support coordinated disaster response. Business Missions for fire and flood scenarios were executed, validating the integration of components such as drone planning, fire/flood simulation, information fusion, and visual analytics. The federated edge-cloud infrastructure, built on lightweight Kubernetes (K3s), ensures resilience, low latency, and data sovereignty across partner nodes.

Initial trials have provided valuable feedback, guiding iterative improvements and confirming the platform's operational maturity. As the project enters its final year, the focus will shift to consolidating integration efforts and preparing for the next round of trials in 2026.

TEMA is on track to deliver a next-generation emergency management solution, empowering first responders and decision-makers with intelligent, real-time insights for effective disaster mitigation and response.

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1 Introduction

The TEMA project encompasses a complex technological ecosystem comprising approximately 26 independent technologies developed by European partners, each delivering specialized capabilities across AI, remote sensing, simulation, data fusion, geospatial visualization, and related domains. This heterogeneous and decentralized environment posed significant challenges regarding integration, interoperability, scalability, and maintainability, necessitating a strategic architectural approach to ensure effective system coordination.

TEMA's architecture addresses these challenges through two fundamental design principles: microservices-based architecture and Orion Context Broker serving as the central event-driven communication layer. The microservices architecture was strategically selected to enable component decoupling, where individual services such as fire detection, flood simulation, drone control, and AR visualization operate independently, minimizing integration risks and simplifying maintenance procedures. This approach supports flexible deployment with horizontal scaling capabilities, cloud or edge deployment options, and site-specific customization across pilot locations in Germany, Italy, Finland, and Greece. Additionally, the architecture maintains technology agnosticism, allowing partners to utilize optimal tools and frameworks for their modules while adhering to established API and data exchange protocols.

To orchestrate microservice interactions, Orion Context Broker, a FIWARE ecosystem component, serves as the central event broker enabling real-time interoperability together with MinIo as object storage. OCB maintains shared digital system state representations including sensor status, fire front detection, and flood prediction areas through context-aware communication. The system employs asynchronous messaging via NGSI-LD, allowing microservices to publish state changes and subscribe to relevant updates, promoting loose coupling and system robustness. NGSI-LD supports rich, linked-data representations that facilitate semantic interoperability across components and domains, while dynamic extensibility enables new services to integrate seamlessly by subscribing to context updates or publishing events.

This architectural combination enables TEMA to effectively manage complex, independent technological components while ensuring seamless integration, real-time information sharing, and the agility required for advanced, distributed, scalable emergency management solutions across Europe. The approach supports scalability through service addition without existing system disruption, maintains resilience by isolating service failures, ensures interoperability across multiple languages, platforms, and data sources through NGSI-LD compliance, and provides future-proofing capabilities for dynamic evolution including new sensors and AI models.

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2 Overview of the integrated platform

The TEMA platform, designed to address the complexities of disaster prevention, management, and response, is inherently positioned to handle the immense challenges of big data in the context of extreme events like floods and forest fires. This platform is tailored to meet the essential requirements of collecting and integrating a vast array of data from heterogeneous sources such as satellite imagery, drone-captured data, smart sensors, and geosocial media. TEMA's advanced data collection mechanisms are equipped to manage the sheer volume and variety of unstructured data, exemplified by the significant storage needs of high-resolution drone videos and satellite images. Furthermore, the platform incorporates scalable storage and processing capabilities, crucial for handling the high velocity and variability of data generated during such catastrophic events. This includes efficient data compression techniques and high-performance computing infrastructures. Beyond mere data aggregation, TEMA ensures the cleansing, normalization, and standardization of data to maintain consistency and precision, thereby facilitating comprehensive and meaningful analysis. The deployment of advanced analytical techniques, including machine learning and artificial intelligence, within TEMA, underscores its capability to derive actionable insights crucial for predicting disaster spread, identifying at-risk areas, optimizing resource allocation, and supporting prompt decision-making. In essence, TEMA is not just equipped to deal with big data; it is also meticulously engineered to harness and analyse this data effectively, making it an indispensable tool in the realm of disaster management and mitigation.

In this section, we will first look at the logical architecture of the TEMA platform, i.e. which components make up the data processing stack and how they are constructed. After that, we will provide a summary description card for each component with its features and inputs and outputs. Finally, we will describe the business missions for fire and flood, which show us how these components are connected to each other in the scenarios examined.

2.1 Updated Platform Architecture

The first version of TEMA Platform Architecture was defined in the D2.2. Here we provide an updated version of the architecture, exploiting the several Hackathons organised to set up the execution environment and the integration of all technical components, as well as the first feedback coming from the Trials performed in each pilot.

2.1.1 Logical Architecture

The TEMA logical architecture (Figure 1) aims to be straightforward and adaptable to accommodate the diverse requirements of various Pilots and, more broadly, to be suitable for various scenarios where heterogeneous data sources and various types of field sensors are utilized. Before going any further, a premise is needed. The logical components will be described without taking into account the deployment modality, which can be in the cloud or in the edge and will be dynamically managed with the mechanisms we will explain in the next section.

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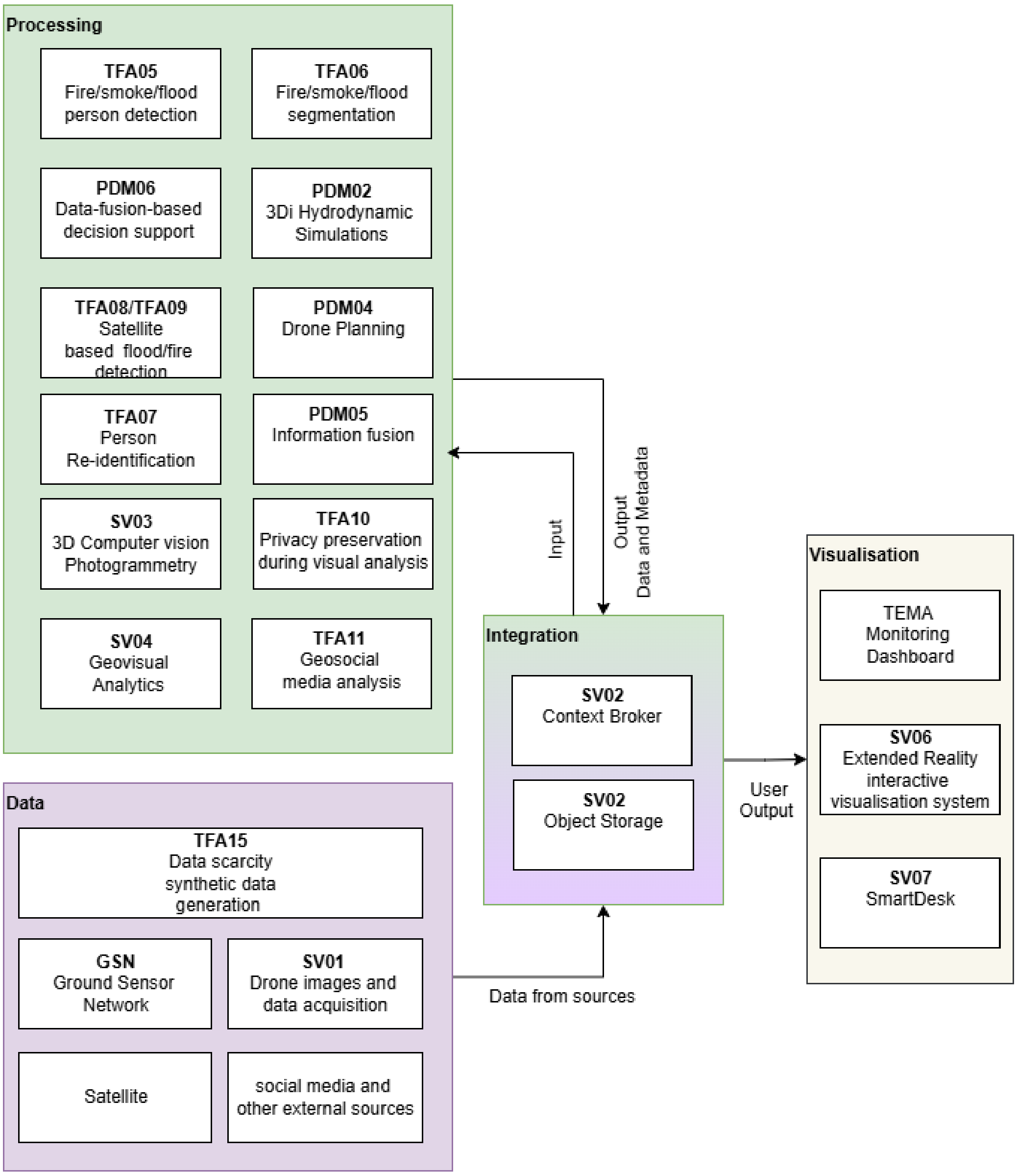

Figure 1: TEMA architecture logical view

Data layer

The Data layer contains all possible data sources useful for disaster management such as open data repositories, structured data acquired from external services or legacy systems, and in general any data of interest, for example sensor data, satellite images, videos and streams acquired from cameras, drones or field operators' information, etc. You can also rely on TEMA's specific technology for generating synthetic data when sufficient data is not available.

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Integration layer

The Integration layer is in charge of:

1. collecting and unifying data from the various sources,
2. storing data resulting from the processing performed by the TEMA tools,
3. providing a publish/subscribe mechanism for the purpose of triggering different tools in a processing chain,
4. support workflow management and scheduled execution of tool/services.

The main component of this layer is the Context Broker, which leverages on JSON-LD (a JSON-based serialization format for Linked Data) to manage context information in a uniform manner and provides the publish/subscribe mechanism via its API based on the NGSI-LD ETSI standard .

As illustrated in the reference architecture [TEMA Deliverable D2.2], the Broker can be used in different ways depending on the specific conditions and constraints, taking advantage of its ability to collect data and its publish-subscribe mechanism:

a) as a metadata register, containing integration information to facilitate the retrieval and invocation of (data/processing) services or to hold configuration information useful for dynamic instantiation of devices,
b) as a real data repository, using NGSI-LD to facilitate the integration of components using different formats,
c) and as a publish/subscribe information broker.

In this way TEMA architecture is flexible and adapt to the needs of the end users and scenarios.

Processing layer

The Processing layer is implemented through the TEMA edge-cloud architecture that supports the end-user services that will be described in the next section. Such data analysis toolbox contains both generic big data tools and specific analytical tools for disaster management based on AI models. TEMA components provide the possibility to process data in batch and near real-time manner. In the next paragraph, all TEMA components will be described briefly.

Visualisation layer

The Visualisation layer consists of all the high-level services that end-users will use in disaster management scenarios to see and interacts with data. These services will be available to operators in the field and decision-makers managing emergencies from operations centres.

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Smartdesk is the main component of this layer, it's a tool to visualize the current situation on the field. Purpose of Smartdesk software is to be the dashboard to give easy access to the necessary data that is needed and bring everything together for visualization purposes.

Smartdesk views are created to aggregate useful information to keep track of the evolution of emergency situations and significant events; for example, to have the map (in a single/integrated view) with the real-time evolution of a fire in which the buildings at risk and the predicted evolution of the fire front are also highlighted. 3D models are created to represent a specific geographical area and integrate data from different sources, such as sensors, satellites and mobile devices. This data can be used to continuously monitor environmental conditions and detect early warning signals for potential natural disasters, such floods and forest fires, but also other types of extreme events such as earthquakes or storms.

The XR-based system collects and presents all the data obtained by TEMA in a simplified manner to the operator. It combines the geospatial data from the Digital Twin with a geovisual map to create a comprehensive and detailed 3D map in an XR environment or desktop application.

2.1.2 Roles and Responsibilities

The present deliverable is focused on the technical architecture, components and integration mechanisms required for the implementation of the platform. In this context, it is possible to provide only a high-level overview of the technical roles, responsibilities and activities performed by the project partners during development and deployment.

A comprehensive definition of operational ownership, including long-term administration responsibilities, governance structures, transition planning, and training frameworks, falls outside the technical scope of this document. These aspects will be addressed in detail within the Exploitation and Sustainability deliverables, where the organizational, operational and business perspectives will be fully analysed and consolidated.

This document therefore concentrates solely on the technical responsibilities and tasks relevant to system design, configuration, integration, testing and delivery, while deferring all matters related to operational ownership and post-deployment governance to the dedicated exploitation work package.

Two nodes are needed to operate the TEMA platform:

1. TEMA SW administrator (UNIME), and
2. TEMA HW administrator (USE).

TEMA SW administrator is responsible for the administration and operational management of the computational cluster used for processing activities. This includes overseeing the deployment,

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configuration and maintenance of the Kubernetes-based cluster and the Docker containers hosting the processing components. TEMA SW administrator (UNIME) ensures proper resource allocation, performance monitoring and workload orchestration, providing a reliable, scalable and continuously available processing environment. Throughout integration and validation, UNIME supported the partners whose components required execution within the cluster, ensuring alignment with the project's technical requirements.

In cooperation with the TEMA SW administrator, ENG provided and integrated the core platform services that enabled communication, data exchange and orchestration between the various components of the system. Its contribution consisted, among other responsibilities, in deploying and maintaining the Object Storage layer used for data ingestion, persistence and inter-component exchange, as well as supplying the Context Broker, which supported real-time data flows, metadata management and interoperability. ENG ensured full architectural compatibility of these services and worked with partners during integration, testing and troubleshooting to guarantee a stable and standards-compliant interaction framework.

TEMA HW administrator (USE) coordinated the selection, deployment and validation of the hardware resources required on the edge side. This involved identifying suitable edge devices based on performance, connectivity and environmental constraints, overseeing their procurement, installation and configuration, and verifying their compatibility with the software and data-collection components. By ensuring that the edge infrastructure was correctly dimensioned and aligned with the system's architectural and operational requirements, USE provided a robust physical foundation that seamlessly integrated with the central processing environment.

2.2 Main Technical Components

This section provides a brief description of the components that make up the TEMA platform. For each component, it provides a description of the functions they implement and the data they exchange. These components have been integrated into the platform and actively participate in the implementation of business missions.

2.2.1 Drone images and data acquisition

ID	SV-Tech-01
Component name	Drone images and data acquisition

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Description & provided functionalities	This technology is responsible for acquiring images and other data from drones. The technology is executed at the Edge Layer, which is comprised by the drones and the Base Station, which will be used as link to the TEMA system. The drone-based image and data acquisition receives plans after confirmation form the operator from the Smart Desk (SV-tech-07) through the Digital Enabler (SV-tech-02)
Input data (data format and data tipology)	RGB images, IR images, and telemetry from the drones
Output data (data format and data tipology)	Sends RGB and IR images to: Fire/smoke/flood/person detection (TFA-tech-05), Fire/smoke/flood/person background segmentation (TFA-tech-06), Person re-identification (TFA-tech-07), and Privacy preservation during visual analysis (TFA-tech-10). Sends the images through the Digital Enabler (SV-tech-02) to Realistic 3D smoke modeling and fire detection (PDM-tech-03), 3D computer vision/Photogrammetry (SV-tech-03), Extended Reality-based interactive visualization system (SV-tech-06), and smart desk (SV-tech-07).

2.2.2 Digital Enabler

ID	SV-02
Component name	Digital Enabler
Description & provided functionalities	The Digital Enabler provides two main functionalities: • Object storage • Context information management Storage is provided by MinIo an open source, distributed object storage server designed to efficiently manage large volumes of unstructured data such as images, videos, documents, logs and backups, it offers an API fully S3 compatible. Context data management component of the entire life cycle of context information provided through Orion-LD that supports the NGSI-LD API following the ETSI CIM specification. Orion also provides a publisher-

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	subscriber mechanism that allows different components to use outputs seamlessly in order to manage the information flow among all the components.
Input data (data format and data tipology)	For Data Storage any type of data For Context Management NGSI-LD Entities
Output data (data format and data tipology)	For Data Storage any type of data For Context Management NGSI-LD Entities

2.2.3 Smart desk

ID	SV-tech-07
Component name	Smart desk
Description & provided functionalities	Smartdesk is a software for disaster response management and collaborative work. It provides a user interface with touch control capability. Visualizes all data provided by TEMA-partners and displays them in Smartdesk map layers Users can create new alerts, define the area affected by the alert, and for example, set the ignition point of a fire. These alerts are then converted into missions. Users can view existing missions and access received data, such as: simulation data, drone imagery, information fusion, UAV-trajectory, Social media posts, Visual analytics data and 3D-models.
Input data (data format and data tipology)	GeoJSON, JSON, TIFF, TIF, KMZ, JPG, PNG, B3DM

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Output data (data format and data tipology)	GeoJSON

2.2.4 Wildfire Analyst – FireSim

ID	PDM-tech-01
Component name	Wildfire Analyst - FireSim
Description & provided functionalities	Wildfire Analyst - FireSim provide wildfire behaviour outputs like arrival time, rate of spread, fireline intensity, flame length or fire paths exportable in GeoTIFF or KMZ, depending on the selected output. A standard simulation is run considering the scenario data, weather forecast and ignition points. When real-time data is available (local weather data and fire fronts locations), a calibrated simulation is calculated adjusting the fire spread with the actual weather and fire behaviour information.
Input data (data format and data tipology)	- Scenario data: fuel model layer, fuel moisture values, DEM, weather forecast values. These inputs are embedded in FireSim. The location of the ignition point or points from the alert is also required as input. - Real-time weather data, from ground sensors component (csv format). - Maps4Fire, from Information Fusión component (GeoTIFF format)
Output data (data format and data tipology)	Output data that is generated by this component are: - GeoTiff files (all fire behaviour outputs) - KML files (arrival time output) TSYL outputs are in compliance with OGC GeoTIFF and KML Standards.

2.2.5 3Di Hydrodynamic Simulations

ID	PDM-tech-02

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Component name	3Di Hydrodynamic Simulations
Description & provided functionalities	PDM-tech-02 provides the following functionality: - Forecasted simulation of the flood propagation based on a meteorological forecast 3Di is a hydrodynamic simulation software, which is used as modelling tool in water management studies. It allows end-users to simulate real-world scenarios and make adjustments to them. Therefore, water experts can predict and mitigate the impact of pluvial, fluvial and coastal floods.
Input data (data format and data tipology)	Input data that is used by this component are: - OGC GeoTiff files (elevation models, friction and infiltration rasters) -Meteorological timeseries (csv) - Hydrological measurements (csv)
Output data (data format and data tipology)	Output data that is generated by this component are: - OGC GeoTiff files (water depth maps, flow velocity maps) - OGC WMS/WFS maps - OGC 3D Tiles for Digital Twin Viewers

2.2.6 Drone Planning

ID	PDM-tech-04
Component name	Drone Planning
Description & provided functionalities	The drone planning's functionality is to optimally plan the trajectories of drones and deployment of sensors suitable for monitoring. The technology will allow autonomous navigation of the drones to optimal sampling locations in order to facilitate data collection.
Input data (data format and data tipology)	Forest fire predictions, flood predictions, obtained from PDM-tech-05 (information Fusion) in GeoTiff
Output data (data format and data tipology)	Drone trajectories to be shown to the human for validation in GeoJson

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2.2.7 Information Fusion

ID	PDM-tech-05
Component name	Information Fusion
Description & provided functionalities	The information fusion fuses various hetorgenous sources of information to obtain an accurate monitoring of monitored natural disater (Flood/Fire).
Input data (data format and data tipology)	Inputs: Processed images (JPG, JPEG, PNG), metadata stored as JSON/GeoJSON, GeoTiff, geojson, href, gpkg.
Output data (data format and data tipology)	Outputs: GeoTiff and GeoJSON

2.2.8 Data-fusion-based decision support and process triggering

ID	PDM-tech-06
Component name	Data-fusion-based decision support and process triggering
Description & provided functionalities	Innovative data-fusion-based decision support service for early remote sensing data acquisition and processing. Fully automatic processing of open web data (e.g. official warnings) and flood and wild fire modeling results; Detection of disaster AOIs and event times; Fully automatic retrieval of satellite position and acquisition data; Generation of decision proposals with information on when and which remote sensing data will be available for a crisis region.

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Input data (data format and data tipology)	Public disaster alerts (provided over REST APIs by GDACS and others); Disaster simulations (provided by TEMA partners TSYL and NS); Satellite acquisition data (provided by DLR over gRPC)
Output data (data format and data tipology)	Human-readable decision proposals (e-mail or any other channel in text-based format); JSON; Machine-readable geospatial data fusion product (GraphQL)

2.2.9 Human-comprehensible presentation of concept-based explanations

ID	TFA-tech-02
Component name	Human-comprehensible presentation of concept-based explanations
Description & provided functionalities	This component provides human-comprehensible presentation of concept-based explanations in the form of heatmaps for two types of predictions made by the components TFA-tech-05 and TFA-tech-06: • Object Detection of Vehicles and Persons • Segmentation of Flood and Fire The input is a drone image delivered by SV01, and the ouput is a heatmap image uploaded on minIO that explains the detection and segmentation results from TFA-tech-05 and TFA-tech-06 for this image in terms of most relevant visuals concepts (shapes, colors) used by the prediction model for making the prediction decision, and whether this concept profile is ordinary for the model, or is likely to constitute an outlier prediction. Subsequently, the heatmap image can be rendered on the SmartDesk next to the predictions from TFA-tech-05 and TFA-tech-06. This visualization is primaliry intended for technical partners to allow for model debugging and improvement, and is also accessible to end-users.
Input data (data format and data tipology)	Input data that is used by this component are images with following format: PNG (ISO/IEC 15948:2004), JPEG (ISO/IEC 10918-5:2013)
Output data (data format and data tipology)	Output data that is generated by this component are images with following format: PNG (ISO/IEC 15948:2004), JPEG (ISO/IEC 10918-5:2013)

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2.2.10 Fire/smoke/flood/person detection

ID	TFA-tech-05
Component name	Fire/smoke/flood/person detection
Description & provided functionalities	DNN-based methods for fire/smoke/flood/person detection/recognition.
Input data	Drone based Imagery of any format (RGB)
Output data	Bounding Boxes of detected objects and their respective class. Data are distributed as notifications though the Context-Broker - Standard: OGC/Geo-JSON-LD - Filetype: .json

2.2.11 Fire/smoke/flood/person detection Semantic segmentation

ID	TFA-tech-06
Component name	Fire/smoke/flood/person detectionSemantic segmentation
Description & provided functionalities	Semantic segmentation could serve for producing fire/flood and background masks.
Input data	Drone based Imagery of any format (RGB or IR)
Output data	Segmentation Masks of areas of interest and seperation of them from the background. - Standard: OGC/Geo-JSON-LD - Filetype: .json, .png

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2.2.12 Person re-identification

ID	TFA-tech-07
Component name	Person re-identification
Description & provided functionalities	The technology implements a person re-identification and tracking system based on deep embedding vectors. For each detected individual in an input image, a unique feature embedding is computed and assigned a corresponding unique identifier (ID). These embeddings are stored in a reference database. For subsequent images, the system performs vector similarity matching between new detections and stored embeddings to re-identify existing individuals or assign new IDs to previously unseen ones. The resulting detection–ID associations are compiled and exported as a structured JSON output file, enabling seamless integration with downstream analytics or tracking pipelines.
Input data	Input data that is used by this component are images with following format: PNG (ISO/IEC 15948:2004), JPEG (ISO/IEC 10918-5:2013), and Person detection as a JSON file
Output data	JSON file with person detections and ID information

2.2.13 Satellite-based flood detection and assessment

ID	TFA-tech-08
Component name	Satellite-based flood detection and assessment
Description & provided functionalities	Machine-learning-based flood processor that derives surface water extent from Copernicus Sentinel-1 (radar) and Sentinel-2 (multi-spectral) satellite images at 10 m pixel spacing.

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Input data (data format and data tipology)	Satellite images (Sentinel-1/-2 through Copernicus Open Access Hub and DLR receiving station using direct broadcast mode); auxiliary data (Copernicus DEM); Cloud-optimized GeoTIFF format
Output data (data format and data tipology)	Surface water extent; OGC WMS, STAC, Cloud-optimized GeoTIFF formats

2.2.14 Satellite-based forest fire detection and assessment

ID	TFA-tech-09
Component name	Satellite-based forest fire detection and assessment
Description & provided functionalities	Deep-learning-based burnt area processor for Copernicus Sentinel-3 and MODIS satellite sensors. Near-real time (NRT) burnt area monitoring, enabler for the monitoring of fire evolution over time.
Input data (data format and data tipology)	Optical satellite and aerial images (Sentinel-3 OLCI, Sentinel-2 MSI through Copernicus Open Access Hub and Aqua/Terra MODIS through Sentinel Hub); auxiliary data (NASA FIRMS and ESA WorldCover)
Output data (data format and data tipology)	Burnt areas (NRT) (OGC WFS and GPKG)

2.2.15 Privacy preservation during visual analysis

ID	TFA-tech-10
Component name	Privacy preservation during visual analysis

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Description & provided functionalities	On-the-fly/real-time generating gender-neutral image samples to replace any detected identity identifiers.
Input data (data format and data tipology)	Drone based Imagery of any format (RGB), Bounding Boxes, Segmentation maps
Output data (data format and data tipology)	Blurred Bounding Boxes of detected objects. - Standard: OGC/Geo-JSON-LD - Filetype: .json

2.2.16 Geo-social media analysis

ID	TFA-tech-11
Component name	Geo-social media analysis
Description & provided functionalities	AI-based multilingual analysis of geo-referenced social media data. It provides individual disaster-related social media posts (SinglePostResult) with a timestamp, location, emotion label, image URLs and captions. It also computes hotspots (HotspotResult) of disaster-related posts in a hexagonal H3 grid at resolution 4.
Input data (data format and data tipology)	Textual social media posts (.csv) Columns: message_id, date, text, geom, photo_url
Output data (data format and data tipology)	- SinglePostResult (.geojson): Individual disaster-related social media posts - HotspotResult (.geojson): Grid-based hotspots of disaster-related social media posts - SocialMediaImages (.json): Photo URLs for caption generation by TFA-tech-13

2.2.17 Contrastive image-language models

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ID	TFA-tech-13
Component name	Contrastive image-language models
Description & provided functionalities	This technology leverages contrastive image-language models (CLIP-like architectures) to perform automated image captioning and text-image similarity analysis. For each social media post, the associated image is downloaded and processed to generate a descriptive caption. Both the generated caption and the original post text are then encoded into a shared embedding space, allowing computation of a similarity score that quantifies their semantic alignment. The system outputs a structured JSON file containing the generated captions and corresponding similarity values for each post, facilitating downstream content analysis and multimodal understanding tasks.
Input data (data format and data tipology)	JSON file with social media posts and corresponding image url on the post.
Output data (data format and data tipology)	JSON file with the captions of the social media post image, and similarity value with the post text

2.2.18 Data scarcity, synthetic data generation

ID	TFA-tech-15
Component name	Data scarcity, synthetic data generation
Description & provided functionalities	This technology enables synthetic dataset generation for natural disaster scenarios using diffusion models to produce realistic and diverse imagery of events such as forest fires and flash floods. Generated images are automatically labeled using zero-shot detection and segmentation models, producing annotations such as fire bounding boxes and flood segmentation masks. All generated images and corresponding labels are aggregated into a structured output dataset, providing ready-to-use data for training, testing, and evaluating machine learning models in disaster-related tasks.

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Input data (data format and data tipology)	Reference images or Text Description of the desired scenarios.
Output data (data format and data tipology)	Labelled Dataset of images of the desired scenario

2.2.19 Digital Twin

ID	SV-03
Component name	Digital Twin
Description & provided functionalities	Generates a 3d Modell from drone images.
Input data (data format and data tipology)	Recieves RGB images from SV-Tech-01
Output data (data format and data tipology)	Outputs a 3d Tileset for SV-tech-07 Smart desk and XR Viewer

2.2.20 XR Viewer

ID	SV-tech-06
Component name	XR Viewer

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Description & provided functionalities	XR Viewer is a VR/AR application for disaster response management and immersive collaborative work. It provides an intuitive XR interface with hand-tracking and gesture control. Visualizes all data provided by TEMA-partners and displays them as interactive 3D map layers in virtual or augmented space. Users can view existing missions in immersive 3D and access received data, such as: simulation data, drone imagery, information fusion, UAV-trajectory, social media posts, visual analytics data, and 3D-models—all rendered in real-time within the XR environment.
Input data (data format and data tipology)	GeoJSON, JSON, TIFF, TIF, KMZ, JPG, PNG, B3DM
Output data (data format and data tipology)	GeoJSON

2.2.21 Visual Analytics

ID	SV-tech-04
Component name	Visual Analytics
Description & provided functionalities	The Geovisual Analytics component is designed to facilitate the rapid retrieval, processing, and visualization of large-scale geospatial data within a cluster-based system. It is an event-driven system component designed to efficiently extract, transform, and load (ETL) large-scale geospatial data to support detailed analysis and visualization. - Geospatial Information Retrieval: Implements advanced content-based retrieval algorithms to efficiently extract relevant geospatial data. - Semantic Annotation: Uses AI-driven techniques to enhance geospatial metadata, improving searchability and data categorization. - REST API for Geovisual Analysis: Provides accessible endpoints via FastAPI for seamless integration with external systems. - Geospatial Computation & Analytics: Supports core spatial analysis

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	operations, including: - OpenStreetMap (OSM) search for location-based queries. - GeoTIFF to COG (Cloud Optimized GeoTIFF) conversion for efficient remote sensing data handling. - Distance-to-nearest point calculations for spatial proximity analysis. - Zonal statistics for extracting summary information within defined geographical regions. - Dashboard Integration: The system supports visualization capabilities through the TEMA dashboard (SmartDesk).
Input data (data format and data tipology)	Data typology: The component subscribes to notifications from the Context Broker related to specific NGSI-LD entity types, such as: - DroneImage: Data from drones, including images and metadata. - Maps4Fire: Information on fire-related maps, such as perimeters and propagation models. It also consumes vector layers (e.g., critical assets) and raster files. - Data format: Communication occurs via JSON entities. The actual data files retrieved include formats like GeoTIFF, GeoJSON, and GeoPackage.
Output data (data format and data tipology)	Data typology: The component creates or updates new NGSI-LD entities in the Context Broker, including: - DistanceFromFire: Indicates the distances between specific resources and the fire front. - DistanceFromFlood: Records the distances between sensitive areas and flooded zones. It also produces analytical data files, such as feature collections, Cloud Optimized GeoTIFFs (COGs), and Parquet tables. Data format: The outputs are JSON (NGSI-LD) entities that contain URLs to the data files. The formats of the generated files include GeoJSON, Cloud Optimized GeoTIFF (COG), and Parquet.

2.3 Research-only components

This section describes a smaller group of components that have been developed and used solely for research purposes within the TEMA project.

2.3.1 Concept discovery for latent space interpretability of deep neural networks

ID	TFA-tech-01

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Component name	Concept discovery for latent space interpretability of deep neural networks
Description & provided functionalities	This component was developped for research purposes only. It provides concept-based explanations in the form of heatmaps for an image classification model (EfficientNet) that was trained for binary fire prediction. The prototype was developped to check whether concept-based explanations, as provided by the Prototypical Concept-based Explanations (PXC) method, are applicable to the natural disaster management domain, as prior to TEMA this XAI method was only applied to standard and widely-used non-disaster-related image classification tasks (such as ImageNet, CIFAR-10 and CUB-200). The input is an image from a publicly available dataset (with label either fire or non-fire), and the ouput is a heatmap image that explains the classification result for this image in terms of most relevant visuals concepts (shapes, colors) used by the prediction model for making the prediction decision, and whether this concept profile is ordinary for the model, or is likely to constitute an outlier prediction.
Input data (data format and data tipology)	Input data that is used by this component are images with following format: PNG (ISO/IEC 15948:2004), JPEG (ISO/IEC 10918-5:2013)
Output data (data format and data tipology)	Output data that is generated by this component are images with following format: PNG (ISO/IEC 15948:2004), JPEG (ISO/IEC 10918-5:2013)

2.3.2 DNN robustness

ID	TFA-tech-03
Component name	DNN robustness
Description & provided functionalities	Robustification of DNN learning against input noise/perturbation.

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Input data (data format and data tipology)	Weights of a trained deep neural network (DNN), input samples to the DNN
Output data (data format and data tipology)	New weights of a trained deep neural network (DNN)

2.3.3 Federated Learning

ID	TFA-tech-14
Component name	Federated Learning
Description & provided functionalities	This technologies enables distributed learning over several nodes, beneficing from the reduction of data migration. Indeed, the training data are not sent, in favor of the post-training data, i.e., the weight matrix. One cloud-aggregator server initialize the model and distribute it to several edge-clients nodes. Data are tranined with local data for a small number of epochs and the weights matrices are distributed back to the aggregator. Here, the weigths are aggregated using an aggregation strategy (i.e., Federated Average) and sent again to the clients. This loop is done a number R of rounds. This technology reduces the latency of data migration and computation and resolve the privacy problem due to the sharing of data toward a central database. This technologies was used to achieve the KPI OA4.1.
Input data (data format and data tipology)	Hyperparameters in JSON format and dataset (i.e., images for achieving the KPI OA4.1)
Output data (data format and data tipology)	The model saved in format .pt.

2.3.4 Smoke and Wind Modeling Engine

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ID	PDM-tech-03
Component name	Smoke and Wind Modeling Engine
Description & provided functionalities	A research component developed under the TEMA project, PMD-Tech-03 uses domain-based information to predict the smoke and wind field at given locations. Inputs collected from the field are combined with information about the terrain to further inform first responders with how smoke may evolve
Input data (data format and data tipology)	Domain information: - Digital Elevation Model of Terrain and wind obstacle covers, in GeoTIF format. Sensor Information: Real-Time Information of trace gases, wind speeds, in netCDF format from the GroundSensorNetwork. Fire Information: Detected Alert location from FireSim (PDM-01), potential fire spread in appropriately geocoded kmz/gpkg.
Output data (data format and data tipology)	Smoke Model Concentrations over the domain (GeoTIFF)

2.3.5 Geospatial information retrieval

ID	SV-tech-05
Component name	Geospatial information retrieval
Description & provided functionalities	DNN-based geospatial information retrieval (GIR) algorithms for rapid retrieval of large-scale geospatial data.
Input data (data format and data tipology)	Drone based Imagery of any format (RGB)
Output data (data format and data tipology)	Retrieved geospatial data (e.g. .geojson) - Standard: OGC/Geo-JSON-LD - Filetype: .geojson

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2.4 Business Missions

Business Missions (BMs) encompass comprehensive assessments for pre-event planning, real-time management during the event, and post-event analysis and assessment. These missions are designed with a high degree of flexibility, primarily focusing on enhancing interoperability among various devices, AI tools, and software solutions. This objective is achieved by setting minimum interoperability standards and optimizing the integration of these elements within a seamless cloud and edge data and processing environment. Such a strategy ensures a harmonious and efficient workflow across different platforms and technologies. Importantly, these business missions are not set in stone; they are adaptable and subject to modification based on evolving end-user needs and insights gained from the initial trial phase. This approach allows for continual refinement and optimization of the missions to better align with real-world applications, ensuring that the missions remain relevant and effective in achieving their intended outcomes. This section describes the basic BMs for fire and flood refined after the preliminary versions defined in D2.2 to adapt to the pilots' scenarios.

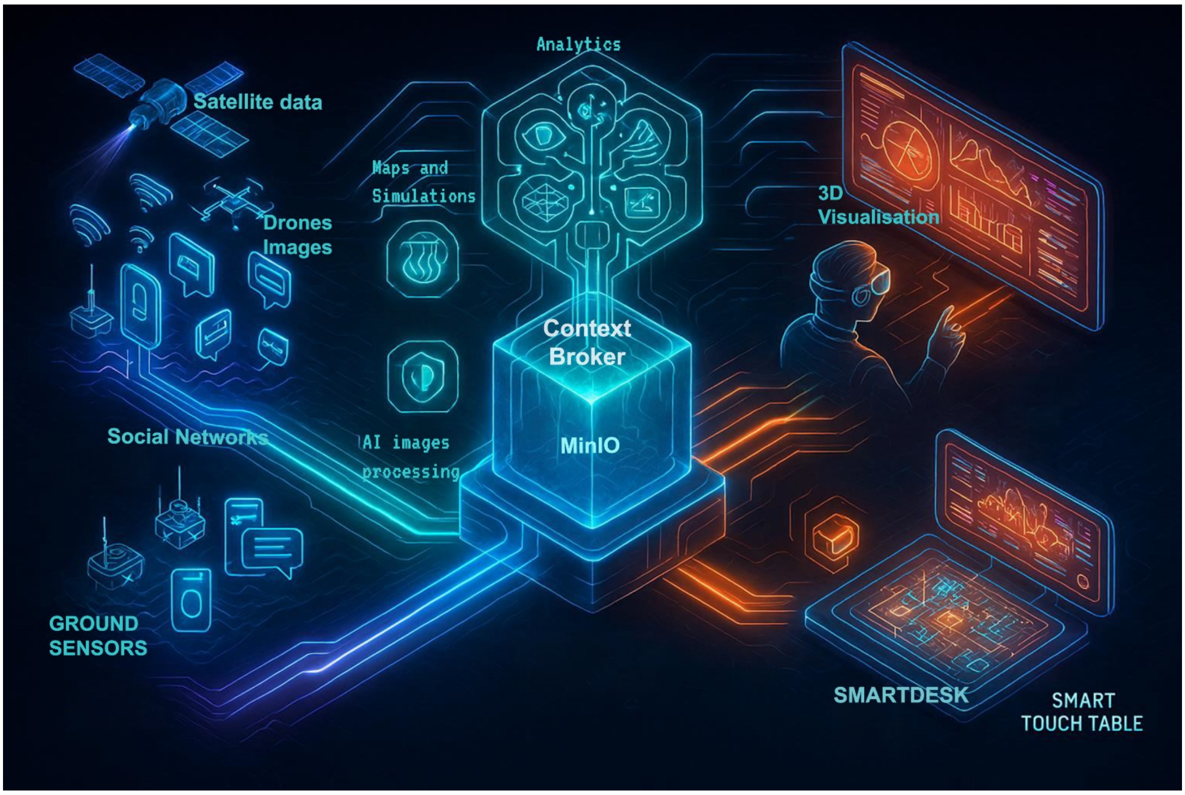

Figure 2: Business Mission high-level flow

Figure 2 is designed to give an intuitive, visually oriented sense of how the architecture operates in practice. Instead of presenting every technical component, it shows the main idea behind

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addressing a particular BM: different data sources, such as satellite observations, drone imagery, IoT ground sensors, synthetic datasets, and social-media signals, feed into a unified integration layer. From there, the combined data stream is processed by the AI components, which perform tasks like environmental detection, scenario simulation, privacy protection, and decision support. The output of these analyses is then routed toward a set of advanced visualization interfaces, including dashboard displays, interactive AR/VR tools, and SmartDesk, a spatially aware touch table. The goal of the illustration is to help a reader intuitively understand how raw, heterogeneous data is transformed into actionable insights.

The complementary TEMA logical architecture diagram (Figure 1) provides the formal technical view of the same architecture. That representation breaks the system down into its explicit modules, interfaces, and data flows, offering a precise definition of how the components interact at an engineering level. When considered together, these two visuals give both a conceptual overview and a detailed technical reference for understanding the architecture.

2.4.1 Business Missions description

In line with specific end-user requirements and the capabilities provided by TEMA technical partners, the TEMA initiative establishes two preliminary Business Missions: Flood and Fire. Each mission defines clear purpose, objectives, and measurable outcomes tailored to its hazard context. The missions cover all phases. Before an event, we focus on risk analysis, preparedness planning, data preparation, and scenario design. During an event, the emphasis shifts to real-time situational awareness, decision support, and coordinated tasking across agencies. Following an event, standardized evaluations and impact analyses are completed, and the results are integrated into updated readiness plans. A central design principle across both missions is robust interoperability. Devices, AI services, and software components communicate through minimum interoperability standards and integrate within a unified cloud and edge data and processing environment so that information moves reliably and actions can be orchestrated without platform lock-in or manual handoffs. The architecture is deliberately flexible to accommodate evolving tools, new data sources, and partner technologies, ensuring that one backbone can support the distinct operational realities of floods and wildfires while maintaining consistent governance, security, and performance. These missions are intentionally iterative rather than final versions. They will be adjusted as end-user needs evolve and as evidence from the initial trial phase indicates where scope, workflows, models, and interfaces should be refined to match real-world conditions. High-level overviews of the two missions will be shown in Figure 2 for Flood and Figure 3 for Fire, offering a concise visual summary of objectives, phases, and data flows.

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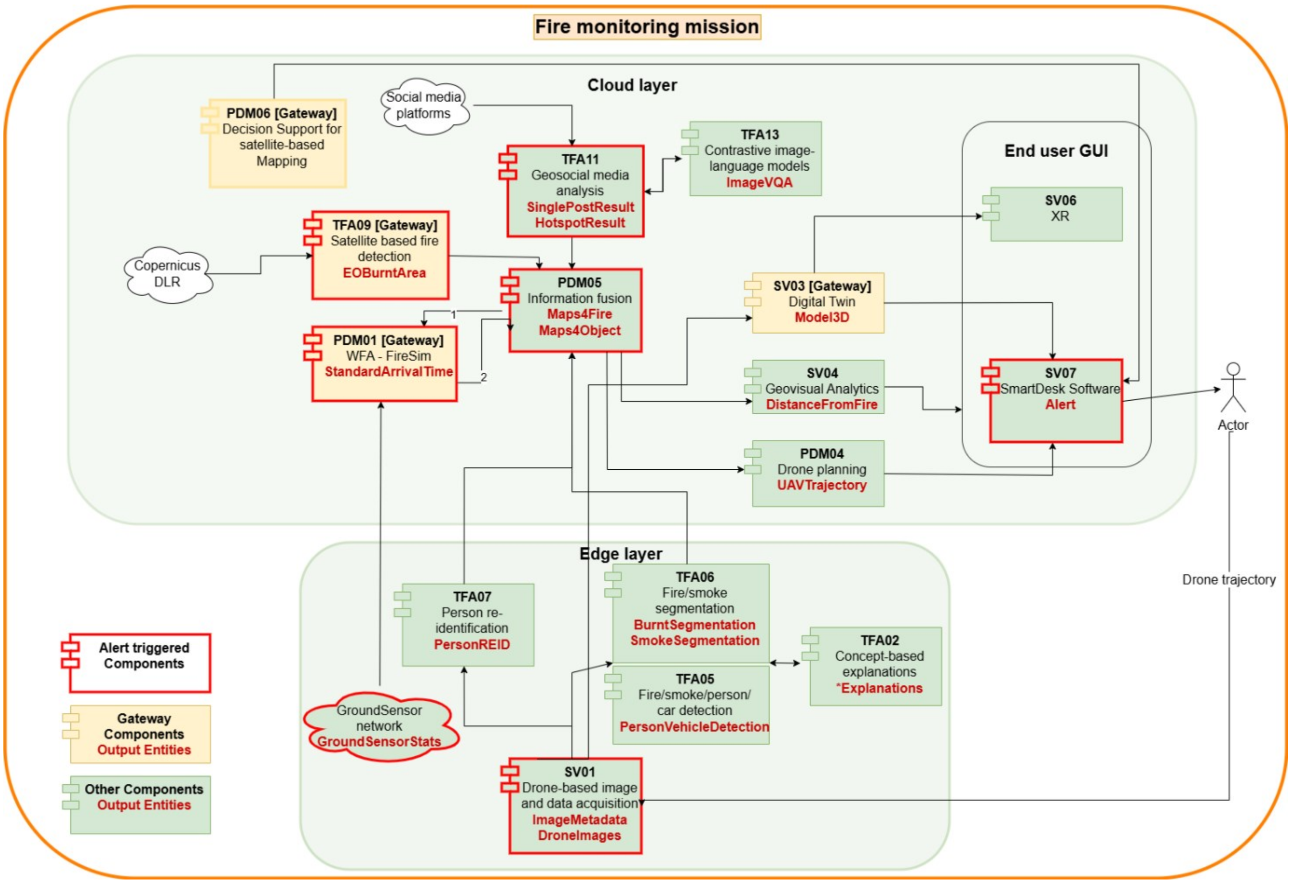

Figure 3: TEMA platform initialization for Fire monitoring

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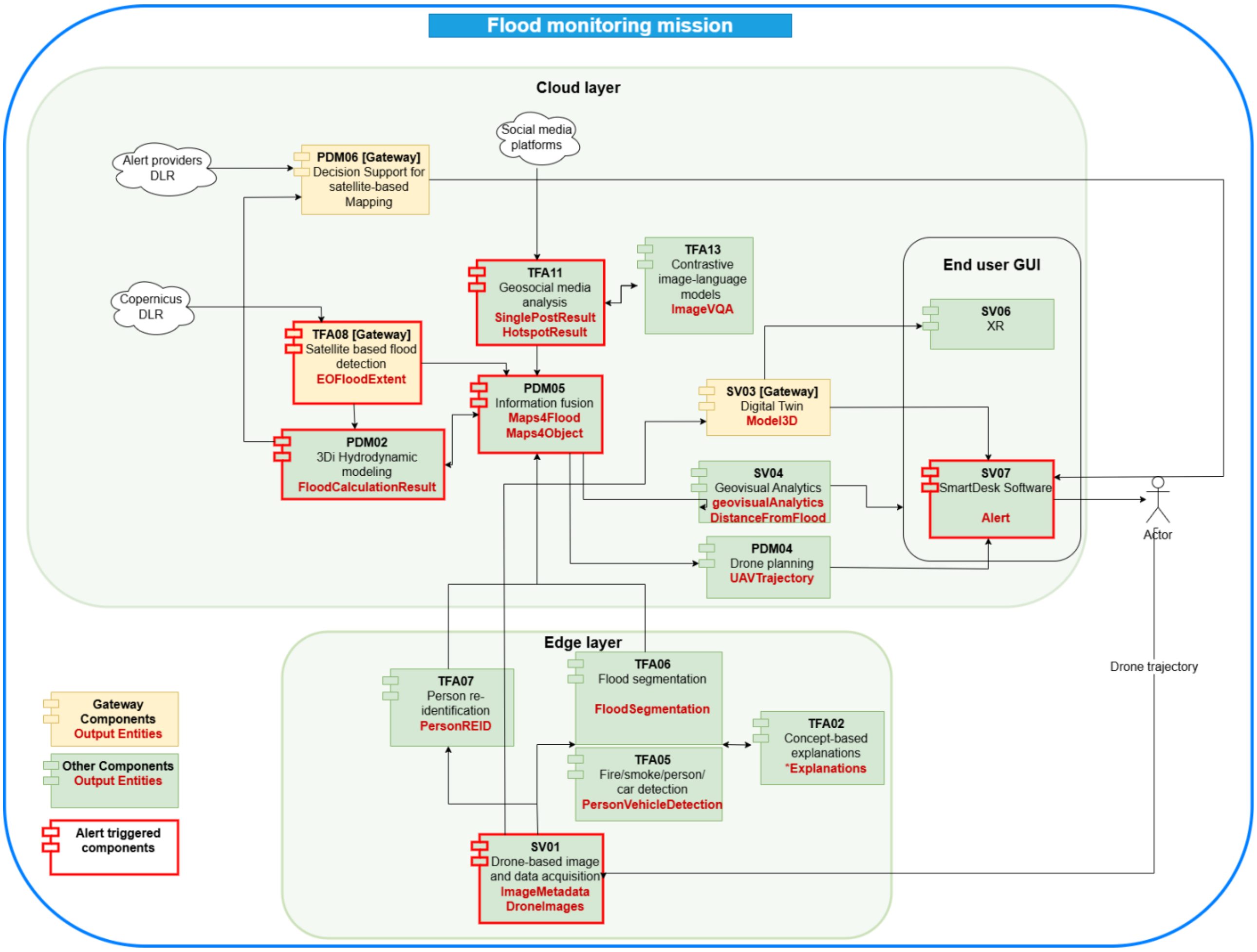

Figure 4: TEMA platform initialization for Flood monitoring

Pre-event Mission

In response to public alerts and meteorological warnings, the platform administrator, well-trained in TEMA's technical solutions, utilizes the TEMA Admin GUI running either on SmartDesk or on a regular computer, to manually plan the drone flight mission. This is carried out to capture images necessary for creating a Digital Twin for the area of interest. In situations involving flood-related alerts, 3D hydrodynamic modelling software can be used to simulate the transition from a warning stage to an actual emergency scenario. The Smartdesk is a mission management application that is installed on a computer in the control room. The basic components of the Smartdesk application are maps, current weather, map measuring tools, map annotations. In addition to those basic tools, the Smartdesk visualises other data sources and technologies in the TEMA project. That information is visualised precisely on the map. For example, the map shows fires or floods, where photos were taken, drones are flying and their planned route, risk zones, and more.

Event Monitoring Mission

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Upon confirmation that the anticipated emergency is underway, the administrator, being at the control room, activates the TEMA platform using the TEMA Admin GUI. Depending on the type of emergency, two specific services are available within TEMA: 1) Fire Monitoring, and 2) Flood Monitoring. Once a particular event monitoring mission is initiated, the TEMA Admin creates an alert that starts the collection of data and the initial data processing, using the necessary technologies, distributing them across the edge or cloud layers of the TEMA platform. The flow of data and the workflow to execute the different technical components at a certain point is depicted in the BM diagrams (Figure 3 and Figure 4).

Control Room

End users in the control room can monitor emergency situations in real-time using a specialized web app either on the SmartDesk or on a regular computer. This app features a 3D situational awareness map, which is based on the constructed Digital Twin and is continuously updated. The map includes multiple layers of information:

- Current Phenomena Layer: displays ongoing emergencies like fires or floods, analysed from drone and satellite imagery.
- Vulnerable Entities Layer: shows the locations of vulnerable individuals and vehicles.
- Predictive Simulation Layer: uses simulation technologies to forecast the progression of the emergency event.
- Alerts and Evacuation Layer: provides warnings and evacuation notices for specific areas as needed.

2.4.2 Data flow and processing

A **Business Mission** represents a coordinated set of activities that technologies and first responders undertake during a natural disaster—such as a flood or wildfire—to continuously assess evolving conditions. Two specific Business Missions have been designed and tested within the TEMA framework: one addressing flooding scenarios and the other focused on wildfire response.

As illustrated in Figure 2, the Business Mission is triggered when an alert is issued. The process begins with human intervention: through the TEMA Solution's web interface, an operator prepares the information required to initiate a Business Mission. This includes details explicitly contained in the alert—such as the affected area (defined by drawing a polygon on the map) and the disaster type (flood or wildfire). The alert creation corresponds to the instantiation of an *Entity* in the **Orion Context Broker**, a core component of the TEMA architecture that orchestrates the data value chain using a **Publish & Subscribe** mechanism.

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Once the *Alert Entity* is instantiated, all components subscribed to it are automatically notified and begin processing the relevant data according to their internal logic. Key components involved at this stage include:

- **Drone-based image and data acquisition**, which collects aerial photographs and videos of the affected zone. The imagery is analysed through dedicated modules for **fire/smoke segmentation** and **fire/smoke/person-vehicle detection** to identify flames, smoke, individuals, and vehicles.
- **Ground Sensor Network**, which gathers meteorological data from stationary or drone-mounted sensors.
- **Fire Simulation**, which models the predicted fire evolution by analysing terrain morphology and fuel availability, estimating fire path, intensity, flame length, and rate of spread.
- **Satellite-based fire detection**, which delineates the burnt area using satellite imagery.
- **Geo-social media analysis**, which collects and processes social media posts to extract emotional indicators—such as fear, sadness, anger, and joy—over time.

The collected information is then harmonised through the **Information Fusion** component, which integrates and analyses all data sources to generate a *probability map* highlighting potential fire locations. This output feeds into the **Visual Analytics** module, which visualises the proximity of residential and public infrastructures (e.g., schools, hospitals, municipal buildings) to the fire zone. Additionally, drone imagery is used to generate a **3D digital model** of the affected area, accessible via an **XR viewer** for immersive exploration by control room operators.

By leveraging AI-powered analytics, the **TEMA Solution** transforms raw, heterogeneous data into actionable insights, empowering first responders and decision-makers to make evidence-based, real-time decisions. In essence, the TEMA Solution acts as the *"eyes"* of the control room, offering a comprehensive and intelligent view of the unfolding disaster.

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3 Tema Edge-Cloud infrastructure

The TEMA Core is the central platform of the TEMA project, designed to enable parallel and distributed processing of large amounts of data from complex and heterogeneous scenarios, typical of *extreme data analytics* applications for natural disaster prevention.

The infrastructure is designed to support large-scale artificial intelligence applications and simulations, ensuring robustness, scalability, and security.

The main objective is not just to aggregate resources, but to create a resilient, federated system. To achieve this result, the TEMA architecture is based on three fundamental strategic choices:

- **Ensures Resilience and Low Latency:** Edge nodes can continue processing real-time data and generating alerts even if the central data center loses connectivity, ensuring critical operations during disasters.
- **Enables Data Sovereignty:** Partners can run computations on local specialized hardware, sharing only aggregated results while retaining full control over their resources.
- **Uses Lightweight Orchestration (K3s):** The platform uses K3s, a lightweight Kubernetes distribution, reducing overhead and simplifying deployment across both cloud and edge environments.

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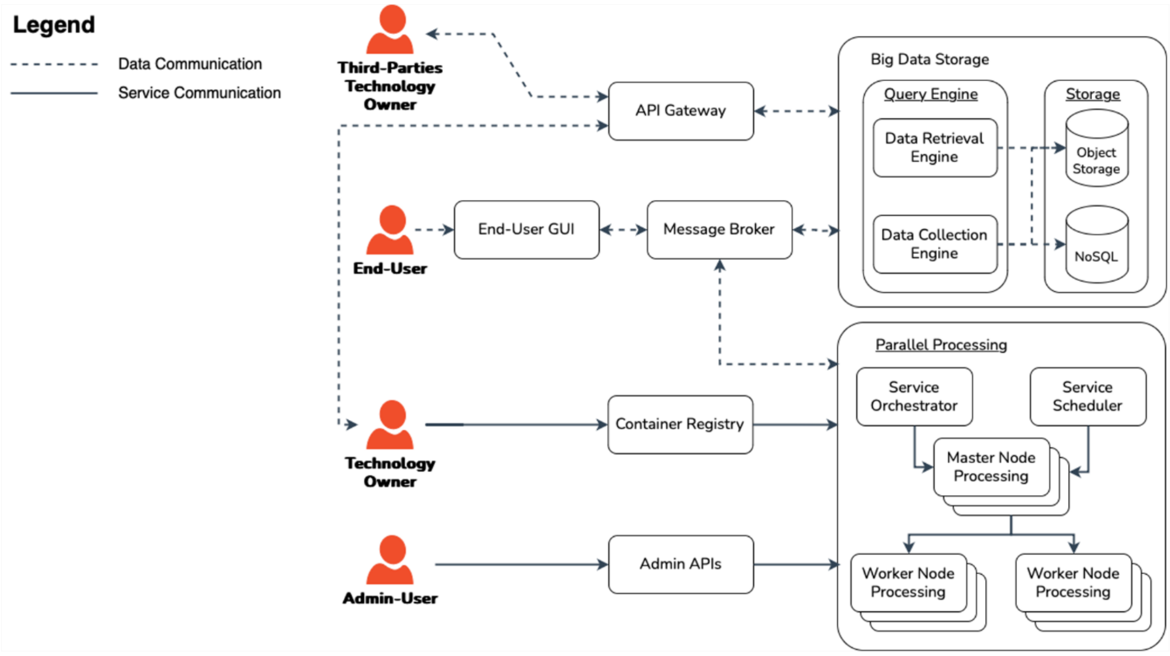

Figure 5: The TEMA Core is a complex infrastructure involving multiple actors, including administrators, end-users, and technology owners. Its main components are the Big Data storage and parallel processing units. The platform is designed to perform massive fed

The platform adopts a microservices approach based on Docker, which allows for modularity, component reusability, and ease of updates. Container orchestration is entrusted to **K3s**, which manages the pod lifecycle, load balancing, and automatic scaling, ensuring system resilience even in the event of hardware or software failures.

Thanks to the Cloud-Edge Continuum paradigm, operations can be balanced between cloud and edge resources, reducing response latency and improving resource utilization efficiency.

3.1 Distributed and Federated Architecture

The TEMA Core is implemented as a federated K3s infrastructure, distributed across multiple computing domains belonging to different partners, ensuring cooperation, redundancy, and flexibility. As shown in Figure 2, this architecture integrates both centralized Cloud resources and distributed Edge devices into a single, unified cluster.

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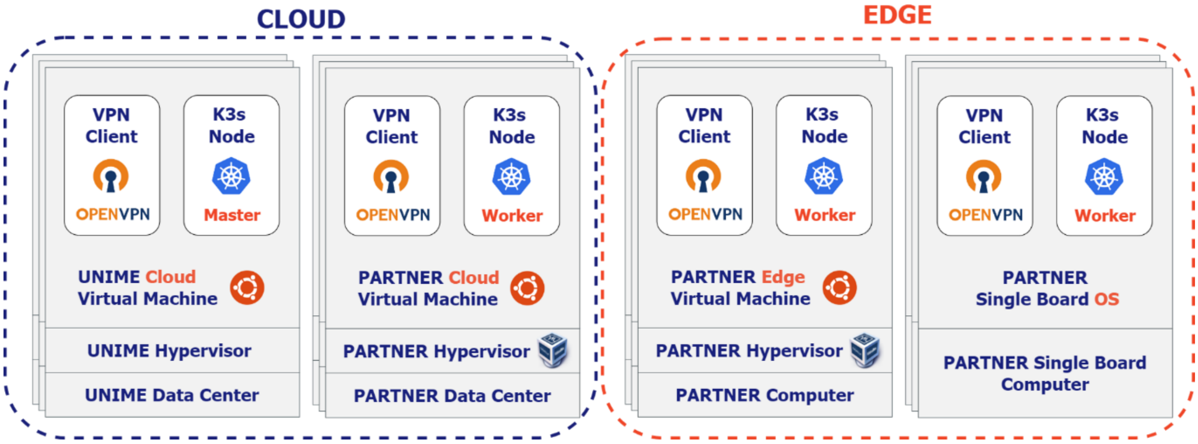

Figure 6: The TEMA Core's federated K3s architecture, illustrating the integration of heterogeneous Cloud and Edge resources.

The federation currently includes:

- **University of Messina (UNIME):** The main node and host of the K3s masters, responsible for global governance and workload management
- **Aristotle University of Thessaloniki (AUTH)**
- **University of Seville (USE)**
- **Atos IT Solutions and Services Iberia SL (ATOS)**

The K3s master nodes at UNIME coordinate workload distribution, resource management, and centralized cluster monitoring. The worker nodes, hosted by the federated partners, execute the containerized microservices according to defined policies.

This federation allows for the use of heterogeneous computational resources, distributing workloads based on availability, priority, and latency requirements. **This heterogeneity is a key feature, allowing the system to span from powerful virtual machines in data centers to low-power Single Board Computers at the extreme edge.** In this way, the system can dynamically adapt to processing needs, also allowing for workload migrations between cloud and edge without service interruption.

3.2 Security, Networking and Service Management

The platform's connectivity and security are guaranteed by a Virtual Private Network (VPN) based on OpenVPN, with the main server located at UNIME.

All master and worker nodes in the cluster have an OpenVPN client that ensures encrypted communications, data integrity, and controlled access to the internal domain.

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To manage access to public services, an NGINX reverse proxy has been implemented, which acts as a centralized entry point (gateway) for all external requests. This overall network and security architecture, which separates the public-facing gateway from the secure internal network, is depicted in Figure 3.

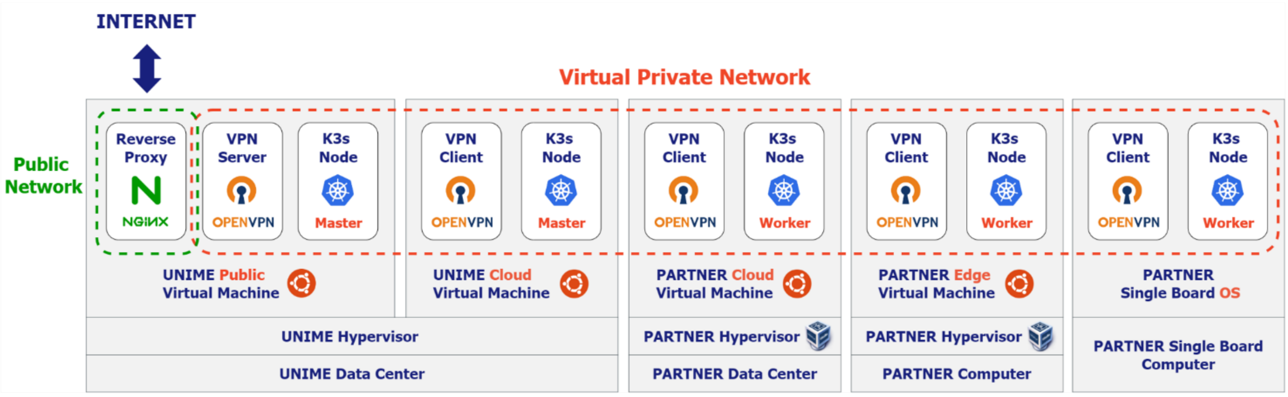

Figure 7: The TEMA Core network architecture, highlighting the NGINX proxy for public access and the OpenVPN-based Virtual Private Network for all cluster nodes.

This component [NGINX] performs crucial functions:

- Routing and load balancing to internal services
- Management of SSL certificates and HTTPS policies
- Application of security and authentication rules for publicly exposed services

To properly manage access and security, the services distributed within the TEMA platform are divided into three main categories:

1. **Public Service (End User Service)**

   Services directly accessible to end-users via graphical user interfaces (GUI) or REST APIs (Representational State Transfer Application Programming Interface) ,e.g., monitoring dashboards).

   Access is via browsers or authenticated REST clients.

2. **Private Service (VPN-only Service)**

   Services available exclusively within the private network via a VPN connection.

   They are primarily intended for developers or operators for internal functions (e.g., databases, logging services).

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All traffic is encrypted, and access is restricted to authenticated users.

3. **Hybrid Services (Private Service with Public APIs)**

These are internal services (running within the VPN) that expose specific public API endpoints (via the NGINX reverse proxy) to allow integration and programmatic communication with external components (e.g., data ingestion from sensors, APIs for other systems).

3.3 Deployment and Microservice Federation

The deployment process for containerized applications in the TEMA Core is based on a federated and policy-driven management, allowing for intelligent workload distribution among the various partners.

Each K3s node is tagged with a series of *labels* describing its characteristics:

- tier: membership level (cloud or edge)
- gpu: availability of GPU resources
- partner: name of the institution owning the node (e.g., partner=AUTH, partner=ATOS)

These labels are used in YAML manifest files (e.g., deployment.yaml) via nodeSelector or affinity rules to constrain the execution of pods to specific nodes.

For example, a service requiring a GPU will be scheduled only on nodes with gpu=true, while a component developed by USE can be run on nodes with partner=USE.

The main K3s resources defined for deployment include:

- **deployment.yaml:** specifies the number of replicas, the Docker image, required resources, and environment variables;

service.yaml: defines internal communication between microservices (via ClusterIP) or exposes the service externally in a controlled manner (via NodePort).

3.4 Node Onboarding

The TEMA infrastructure includes dedicated tools to simplify the integration of new resources into the federated cluster, reducing configuration time and minimizing manual errors. Node onboarding is designed for both developers who want to use pre-configured environments and partners who wish to add existing Linux nodes.

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3.4.1 "Click & Play" VM

The "Click & Play" Virtual Machine is a ready-to-use solution based on Oracle VirtualBox, designed to facilitate immediate entry into the TEMA cluster. Key features include:

- **Pre-configured Environment:** The VM contains Docker, Git, and a local MongoDB instance for microservice development and testing.
- **Automatic Network Configuration:** On first boot, the VM automatically connects to the TEMA VPN, obtaining a valid internal IP address within the cluster's private network.
- **Certificates and Security:** The SSL/TLS certificates necessary for secure communication with internal services and federated nodes are configured automatically.
- **Facilitated Access:** Developers can immediately start deploying containers, interacting with microservices, and testing applications without complex manual configurations.
- **Internal Automation Script:** The VM includes scripts that prepare the environment, update packages, and ensure compatibility with the required K3s and Docker versions.

This solution allows for the rapid integration of new resources without manual intervention, ensuring uniformity and security across all nodes in the federation.

3.4.2 Automatic Join Script for Linux

For partners wanting to integrate existing Linux nodes into the federated TEMA cluster, an automated script is available that completely simplifies the process. Main features of the script:

- **VPN Connection:** Automatically configures OpenVPN on the node, ensuring all communication with other nodes is encrypted and secure.
- **Cluster Registration:** The script registers the node with the UNIME K3s master, assigning the necessary labels (tier, gpu, partner) based on the hardware characteristics and the node's owner.
- **GPU Enablement:** If the node has a GPU, the script configures the NVIDIA drivers and the necessary K3s resources to allow containers to use the GPU.
- **Node Status Verification:** At the end of execution, the script performs automatic checks to verify the VPN connection, visibility in the cluster, and the correct configuration of resources.

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- **Minimal Manual Configuration Required:** The user only needs to run the script with appropriate privileges; all networking, certificate, package installation, and K3s registration operations occur automatically.

Key advantages of the automated approach:

- Reduction of manual errors during node configuration.
- Rapid addition of real computational resources (physical or virtual) to the federated cluster.
- Uniformity in managing labels, GPUs, and the private network connection.
- Ability to dynamically scale the cluster with new nodes without interrupting running services.

3.5 Monitoring, Logging and Cluster Management

The TEMA Core integrates a comprehensive system for monitoring, logging, and centralized management of the K3s clusters to ensure observability, control, and reliability over the distributed resources. This approach provides a complete view of the platform's operation, allows for real-time anomaly detection, and optimizes resource usage, ensuring service continuity even in complex, federated scenarios.

3.5.1 Monitoring with Prometheus and Grafana

Monitoring is based on two main tools: **Prometheus** and **Grafana**, integrated to provide real-time metrics and detailed visual analysis.

- **Prometheus:**
  - Collects metrics from nodes, pods, and Docker containers, including CPU, RAM usage, GPU status, network traffic, application response times, and service availability.
  - Stores data in a time-series database, allowing for advanced queries via PromQL.
  - Allows for the definition of *alert rules*, generating immediate notifications in case of malfunctions, anomalous loads, or performance degradation.
- **Grafana:**
  - Consumes the metrics collected by Prometheus to create interactive and customizable dashboards that visualize the status of clusters, nodes, and individual microservices.

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  - Supports filters by partner, service, or resource type, enabling granular performance analysis.
  - Provides the ability to analyze historical trends, compare time periods, and identify bottlenecks or inefficiencies in workload distribution.
  - Integrates notification systems, such as email or webhooks, to alert administrators.

When used in a tandem, Prometheus and Grafana ensure proactive monitoring and complete visibility, essential in a federated environment like the TEMA Core.

3.5.2 Logging and Debugging with Kubetail

Microservice logging is managed using **Kubetail**, a tool that aggregates logs from multiple pods in real-time. Main features of Kubetail:

- Allows developers to monitor the execution of their microservices without having to manually access each container.
- Displays logs in real-time, with the ability to filter by pod, container, or namespace, facilitating the identification of errors or anomalous behaviour.
- Supports tracing of application flows across multiple pods, useful for debugging distributed services and analyzing interactions.
- Reduces the time needed for diagnostics, increasing operational efficiency.

Kubetail is integrated with the platform's security policies, ensuring that only authorized developers can access the logs for their services.

3.5.3 Centralized Management with Rancher

The overall management of the K3s clusters is entrusted to **Rancher**, a platform that offers an intuitive graphical dashboard for administering multiple federated clusters. Key features of Rancher:

- **Centralized View:** Allows monitoring the status of all nodes (master and worker), pod distribution, and the usage of CPU, RAM, and GPU resources.
- **Microservice Deployment and Updates:** Enables the deployment of new applications, updating existing versions, and managing rollbacks.
- **User and Permission Management:** Defines roles and authorizations for developers, operators, and administrators, ensuring secure and controlled access to the clusters.

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- **Automation and Audit:** Integrates tools for automatic node provisioning, security policy management, and tracking of operational changes.

The integration of Rancher, Prometheus, Grafana, and Kubetail provides a unified and complete view of the entire federated infrastructure, combining monitoring, logging, and centralized management capabilities in a single ecosystem.

This approach ensures:

- maximum reliability and availability of services
- rapid identification and resolution of problems
- continuous optimization of cluster and microservice performance
- granular control over resources and access in distributed, multi-partner contexts

3.6 The TEMA Core in its Applicative Context

The TEMA Core infrastructure described is not a technical exercise in itself; it represents the operational engine that enables the strategic objectives of the TEMA project in the domain of natural disaster prevention, such as fires and floods.

The platform is currently used to orchestrate complex workloads that are fundamental for risk mitigation. These use cases include:

- The **execution** of computationally intensive artificial intelligence models that require access to federated GPU resources.
- The real-time processing of large volumes of heterogeneous data from on-site sensors and other remote sources.
- The execution of complex risk simulations distributed across the various consortium nodes.

The federated K3s architecture and the Cloud-Edge approach have proven crucial for these scenarios. They ensure low-latency data processing and allow for efficient workload allocation, ensuring that the most demanding tasks (such as AI inference) are executed on the most appropriate specialized hardware (e.g., GPUs) available within the federation.

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4 Hardware Integration

Achieving the TEMA's goals mandates the Integrated Operation of TEMA Hardware, which spans a highly heterogeneous set of devices across the entire components. Specifically, deploying and integrating heterogeneous hardware with sophisticated sensing and processing capabilities is crucial for the effective execution of TEMA missions. This integration effort is not merely a matter of connectivity; it is the foundational requirement for TEMA's entire data processing pipeline, which links the Edge to the Cloud-based processing services. Therefore, seamless and reliable information flow among the Edge and Cloud components is of utmost importance. The following sections detail the essential hardware integration, ensuring the collected data is transformed into actionable intelligence rapidly and accurately for the end-user.

4.1 Hardware Components

The TEMA architecture relies on a collection of heterogeneous hardware components strategically positioned across the Edge and Cloud. These components are grouped into six main categories: Drone Platforms, Drone Sensors, Ground Sensors, Edge Computers, Cloud Computers, and Communication Systems. The successful integration of these elements forms the physical backbone of the project's real-time data pipeline. Figure 5 illustrates the functional distribution of hardware, spanning from data acquisition devices (Drones and Ground Sensors) at the far Edge, through the local Base Station/Edge computers (EDGE1-EDGE6), to the centralized Cloud services (CLOUD1-CLOUD13) which host the core partner technologies.

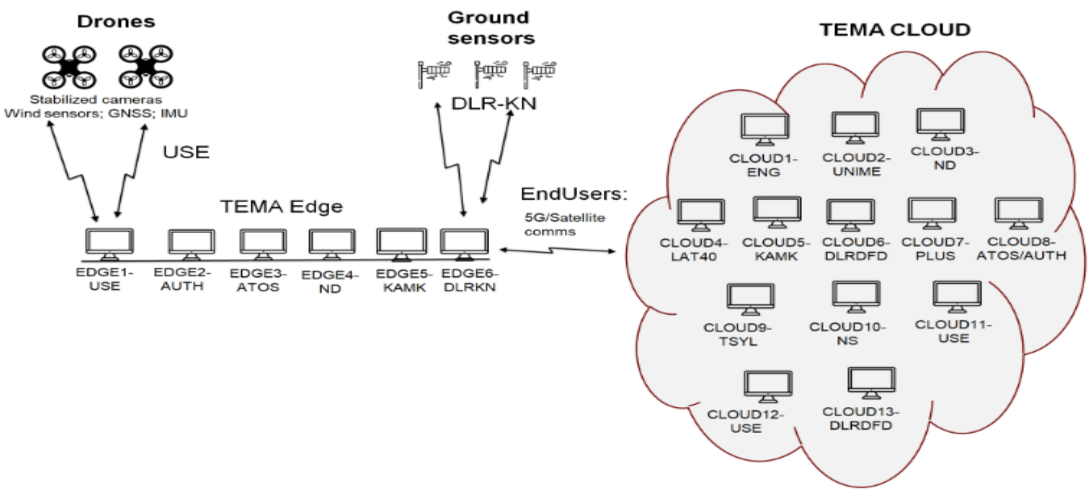

Figure 8: Hardware components and distributed architecture.

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4.2 Hardware Components VS Technologies

The successful integration of TEMA is based on the mapping between the physical hardware resources and the specific software technologies developed by the consortium partners. This relationship defines which partner is responsible for deploying and maintaining which technological service on which physical machine. As illustrated in Table 4.1, the architecture is logically segmented by hardware function (Drones, Ground Sensors, Base Station, and Cloud), clearly showing the ownership (Partner) and the specific technology deployed (TEMA Technologies). This matrix is essential for defining the hardware integration requirements, testing responsibilities, and maintaining traceability throughout the project lifecycle.

Table 4.1: TEMA Hardware component to technology mapping.

	TEMA Techs.	Partner	H/W
Drones		USE	Drone platforms
		USE	Stabilized visual+IR images; GNSS; IMU
Ground Sensors		DLR-KN	wind sensors
Ground Sensors		D.MALIAN	meteorological sensors
Drone Base Station	SV-tech-01	USE	EDGE1-USE
	SV-tech-03	ND	EDGE4-ND
	SV-tech-06	ND	EDGE4-ND
	SV-tech-07	KAMK	EDGE5-KAMK
	TFA-tech-02	FHHI	EDGE2-AUTH
	TFA-tech-05/06	AUTH	EDGE2-AUTH
	TFA-tech-07	ATOS	EDGE3-ATOS
	TFA-tech-10	AUTH	EDGE2-AUTH
	PDM-tech03	DLR-KN	EDGE6-DLR-KN
TEMA Cloud	SV-tech-02	ENG	CLOUD1-ENG
		UNIME	CLOUD2-UNIME
	SV-tech-03	ND	CLOUD3-ND
	SV-tech-04	LAT40	CLOUD4-LAT40
	SV-tech-06	ND	CLOUD3-ND
	SV-tech-07	KAMK	CLOUD5-KAMK
	TFA-tech-08/09	DLR-DFD	CLOUD6-DLR-DFD
	TFA-tech-11	PLUS	CLOUD7-PLUS
	TFA-tech-13	ATOS	CLOUD8-ATOS/AUTH
	PDM-tech01	TSYL	CLOUD9-TSYL
	PDM-tech02	NS	CLOUD10-NS
	PDM-tech04/05	USE	CLOUD11-USE; CLOUD12-USE
	PDM-tech06	DLR-DFD	CLOUD13-DLR-DFD

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4.3 Hardware Mapping

A general overview of the hardware components used in the TEMA architecture is presented, in order to clarify their function and relevance in the platform's implementation. In this section we specify based on the information provided by each corresponding partner, all the hardware elements including: drones, sensors, computer model, power consumption, size, weight, interconnections, among others.

4.3.1 Drone Platforms

The drone platforms have been selected considering the type of missions in TEMA trials (VLOS/BVLOS and others) as well as drone regulations and drone platform technology. Two multirotor models could be used depending on the conditions of each trial: DJI Matrice 210 (M210) and DJI Matrice 300 (M300). Both are robust and professional-grade drones, and provide the necessary stability and endurance to fly repeated missions over large-scale disaster regions. The main technical specifications of the drones are listed in Table 4.2 and Table 4.3.

Table 4.2: Specifications of DJI M210.

Model:	DJI M210
Number of units	2
Drone category:	Open Category A3, Specific Category STS-02
Flight time:	- No Payload, with TB50: Max 27min - No Payload, with TB55: Max 38min - Full Payload, with TB50: Max 13min - Full Payload, with TB55: Max 24min
Flight range:	Maximum transmission distance of 5 miles (8 km) in unobstructed environments free of interference.
Size:	- Unfolded: 887×880×378 mm - Folded: 716×220×236 mm
Weight:	- With two TB50 batteries: Approx. 3.84 kg - With two TB55 batteries: Approx. 4.57 kg
Onboard Sensors:	Zenmuse XT2 Zenmuse X5S Zenmuse Z30
Power requirements:	Utilizes dual hot-swappable TB50 or TB55 batteries. - TB50: capacity: 4280 mAh, voltage: 22.8V, energy: 97.58 Wh - TB55: capacity: 7660 mAh, voltage: 22.8V, energy: 176.93Wh

Table 4.3: Specifications of DJI M300.

Model:	DJI M300
Number of units	2
Drone category:	Open Category A3, Specific Category STS-02

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Flight time:	- No Payload: Max 55min - Full Payload: Max 31min
Flight range:	Maximum transmission distance of 9 miles (15 km) in unobstructed environments free of interference.
Size:	- Unfolded: 810×670×430 mm - Folded: 430 × 420 × 430 mm
Weight:	- Without batteries: Approx. 3.6 kg - With two TB60 batteries: Approx. 6.3 kg
Onboard computers:	Compatible with DJI's Onboard SDK and Payload SDK, allowing integration with various onboard computing devices.
Onboard Sensors:	ZENMUSE H20 ZENMUSE H20T
Power requirements:	Utilizes dual hot-swappable TB60 batteries. Each TB60 battery has a capacity of 5935 mAh, a voltage of 52.8V, and energy of 274 Wh.

4.3.2 Drone Sensors

The aerial platforms carry a wide variety of sensors. For TEMA, we considered a wide range of gyro-stabilized camera systems that include the visible and/or thermal spectrum, for frequent, high-resolution image collection, enabling image acquisition technology. Table 4.4 illustrates the main specifications of the onboard cameras.

Table 4.4: The specifications of the sensors for DJI M210 and DJI M300.

Zenmuse XT2	
Model:	Zenmuse XT2
Drone model:	DJI M210
Stabilized:	YES
Visual camera:	YES
Visual Zoom:	YES, 1x, 2x, 4x, 8x
Infrared camera:	YES
Infrared Zoom:	640×512: 1x, 2x, 4x, 8x 336×256: 1x, 2x, 4x
Zenmuse X5S	
Model:	Zenmuse X5S
Drone model:	DJI M210
Stabilized:	YES
Visual camera:	YES
Visual Zoom:	Does not support internal zoom mechanisms Uses interchangeable MFT lenses
Infrared camera:	NO
Infrared Zoom:	NO

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Zenmuse Z30	
Model:	Zenmuse Z30
Drone model:	DJI M210
Stabilized:	YES
Visual camera:	YES, 6x
Visual Zoom:	NO
Infrared camera:	NO
Infrared Zoom:	DJI M210
Zenmuse H20	
Model:	ZENMUSE H20
Drone model:	DJI M300
Stabilized:	YES
Visual camera:	YES
Visual Zoom:	YES, 23 x.
Infrared camera:	NO
Infrared Zoom:	NO
Zenmuse H20T	
Model:	ZENMUSE H20T
Drone model:	DJI M300
Stabilized:	YES
Visual camera:	YES
Visual Zoom:	YES, 23×
Infrared camera:	YES
Infrared Zoom:	1×, 2×, 4×, 8×

4.3.3 Drone's Onboard Computer

To bridge the gap between aerial data acquisition and processing in the TEMA framework, each drone platform is equipped with a custom Onboard Edge Computer System (OECS). This system is designed for minimal size and weight to comply with drone payload and energy consumption limitations, while providing essential computational capacity for real-time data handling.

The OECS is housed within a custom-designed back bag assembly, which is securely mounted on the top chassis of the multirotor platforms. Figure 6 illustrates the assembly itself, along with its deployment configuration. The core of this system is the Khadas VIM3 single-board computer, chosen for its high performance-to-power consumption ratio, enabling it to function as dedicated unit for image acquisition, adaptation and transmission.

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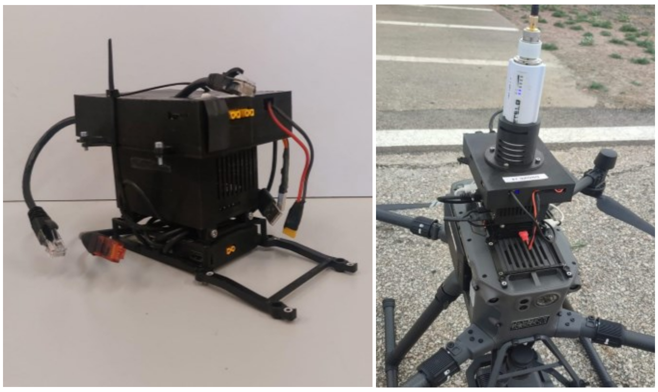

(a) (b)

Figure 9: Onboard Edge Computer System (OECS) Integration. (a) shows the custom-built, compact OECS back bag assembly, detailing the internal components, including the Khadas VIM3 and power/communication interfaces. (b) shows the OECS mounted on the DJI M300 dro

The system's power and communication backbone are facilitated by the DJI PSDK (Payload SDK) developer kit. This kit serves two critical purposes: it provides regulated power directly to the Khadas VIM3 computer and the attached Power over Ethernet (PoE) component, and it establishes a data link with the drone's flight controller via a serial-to-USB port. The OECS software stack is designed to manage data downloading and transporting. It incorporates the DJI PSDK and OSDK (Onboard SDK), allowing the VIM3 to receive and execute high-level commands sent from the Ground Control Station (GCS).

The most critical function of the Khadas VIM3 is image downloading from the camera and transmission. Installed on the Khadas VIM3 is a specialized ROS package responsible for taking the images acquired by the drone's cameras at high rate, performing compression, and preparing them for real-time transport. The actual data transfer to the base station is achieved via a dedicated high-speed WiFi link, utilizing Ubiquity components mounted on the OECS to ensure reliable, high-throughput communication across the operational area. This process establishes the drone as a fully functional edge component capable of feeding critical, compressed visual data immediately into the TEMA pipeline.

4.3.4 GCS-Drone Communications

Reliable and high-bandwidth communication between the Drone Base Station (GCS) and the drones is paramount for the TEMA project, enabling real-time image transfer and command and control. This is achieved through a robust wireless link, primarily utilizing Ubiquiti networking hardware.

The wireless link is established using specialized Ubiquiti radios and antennas selected to provide optimal performance in diverse environments. Table 4.5 provides an overview of the components and their main specifications. It details the hardware components, communication protocol, and performance metrics for the wireless link between the Drone Base Station and the TEMA drones.

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The ground segment of the communication link employs a Ubiquiti Prism Rocket AC Gen2 radio paired with a Ubiquiti UISP Horn 5-6.85 GHz antenna, designed for directional and interference-resistant transmission from the base station. On the drone side, each aerial platform is equipped with a compact Ubiquiti Bullet AC radio and an Alfa Network APA M25 sector antenna.

Table 4.5: GCS-Drone Communication Link Specifications.

Radios:	Ground: Ubiquiti Prism Rocket AC Gen2 On each drone: Ubiquiti Bullet AC
Antennas:	Ground: Ubiquiti UISP Horn 5-6.85 GHz On each drone: Alfa Network APA M25
Onboard Back Bag:	On each drone: Khadas Vim3 Pro, POE, PSDK Development Kit
Protocol:	Air Max AC
Range:	Up to 2 Km
Bandwidth:	30+ Mbps / 5 GHz

The selection of these components ensures a robust communication channel, operating on the 5 GHz band to leverage clearer spectrum and higher bandwidth. The link utilizes the Air Max AC protocol, which is optimized for point-to-multi-point communication, ensuring efficient data flow even with multiple drones operating simultaneously within the main lobe of the antenna. This setup provides an effective operational range of up to 2 kilometers, with a sustained bandwidth exceeding 30 Mbps, crucial for transmitting compressed images in real-time.

Figure 7 visually presents these communication components. The onboard antenna is shown in Figure 7a. Figure 7b shows the compact Ubiquiti Bullet AC and the larger Ubiquiti Prism Rocket AC Gen2, respectively as onboard and ground transmitters. The ground antenna (Figure 7c) depicts the Ubiquiti UISP Horn, highlighting the physical robustness of these outdoor communication units. These components are integral to maintain continuous data flow from the aerial edge to the ground infrastructure.

(a) (b) (c)

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Figure 10: The primary components of the wireless link GCS-drone communication hardware: (a) The Alfa Network APA M25 onboard antenna mounted on the OECS. (b) The Ubiquiti Bullet AC (left, onboard radio) and (c) Ubiquiti Prism Rocket AC Gen2 (right, ground radio)

4.3.5 Drone Base Station Architecture

The drone base station architecture (Figure 8) is designed for both flexibility and robust operational capability, successfully integrating diverse technologies to support the missions. A cornerstone of the design is its support for heterogeneous aerial platforms, which is facilitated by the implementation of specific backends tailored to different vehicle types. To ensure consistency and modularity across the system, the overall software architecture is based on the Robot Operating System (ROS). A critical design consideration for drones is the inherent constraint on resources: there is limited onboard processing capacity directly attributable to strict limitations on payload weight and power consumption. To mitigate this fundamental challenge and enable high-level functions, the architecture strategically delegates intensive computational tasks. This is achieved by making additional computational capacity available in the ground processing core, which handles complex data analysis, mission planning, and other demanding operations, thereby allowing the drones to maintain maximum flight endurance and payload efficiency.

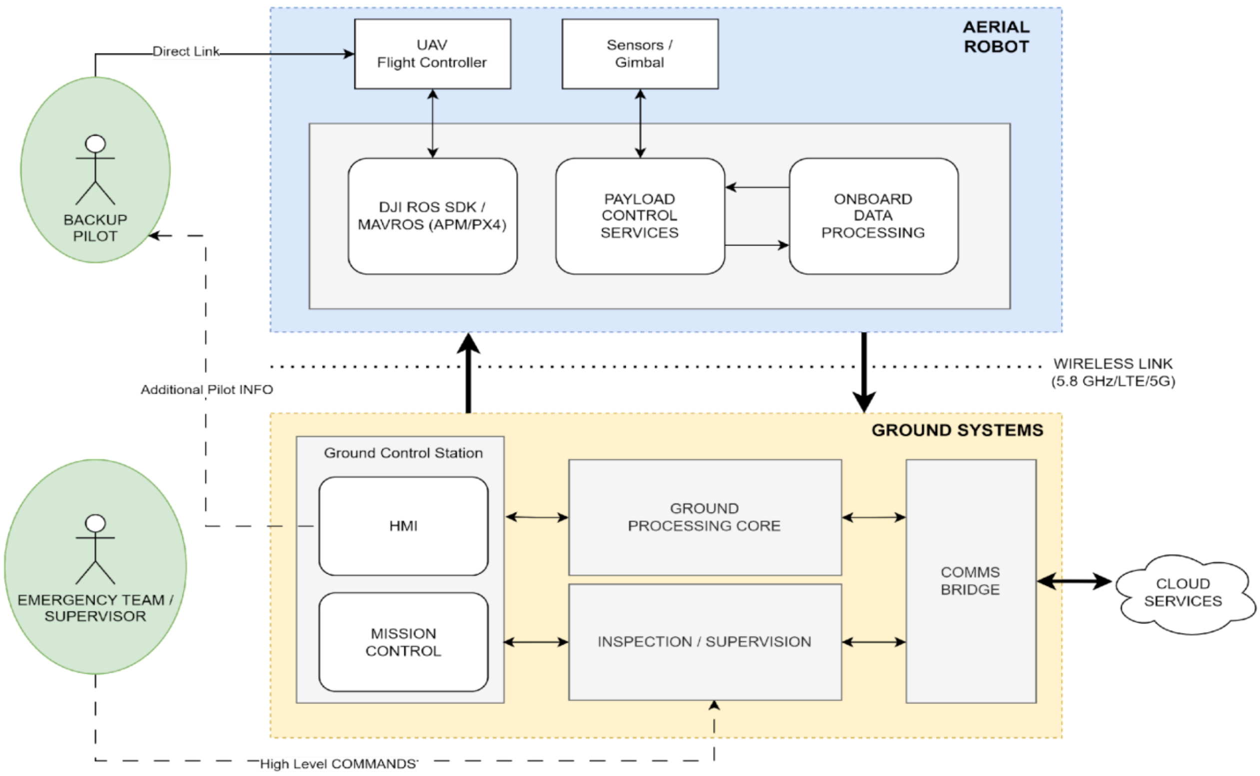

Figure 11: The architecture of the drone base station.

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4.3.6 Ground sensors

DLR-KN Ground Wind Sensors

The wind sensors are provided by DLR-KN and are essential for providing localized wind speed and direction context critical for both drone flight safety and accurate disaster modelling. The ground sensor network is comprised of various units, providing a comprehensive environmental profile. The central meteorological unit is typically an ultrasonic weather station, which provides crucial measurements without moving parts, enhancing reliability in harsh environments. Table 4.7 details the range of sensor models deployed and the specific measurements they contribute. The deployed units measure not only fundamental atmospheric conditions such as wind speed, direction, temperature, and air pressure, but also solar intensity and various air pollutants (Particle Matter(PM) 2.5, PM10, NO_x, SO_2, CO). These environmental parameters are vital inputs for the simulation and fusion technologies in the TEMA Cloud.

Table 4.6: Main specifications of DLR-KN ground wind sensors.

1	**Model:**	Renkeer Ultrasonic Weather Station
	Number of units	3-10
	Measurements	- Wind Speed + Direction (@2m, adjusted to 10m) - Solar Intensity - Temperature
2	**Model:**	Trisonica Mini LI-550
	Number of units	1-3
	Measurements	- Wind Speed + Direction (Research Purposes) - Temperature - Air Pressure
3	**Model:**	Semeatech A-series, EC
	Number of units	3-10
	Measurements	NOx, SO2, CO
4	**Model**	Panasonic SN-GCJA5
	Number of units	3-10
	Measurements	PM2.5, PM10 counts and concentrations
5	**Model**	Raspberry Pi
	Number of units	3-10
	Model	Comp. with ROS2

Establishing reliable communication for these low-power, distributed sensors is handled by a specialized Mobilicom MCU30 long range communication link. The system, detailed in Table 4.8, uses Raspberry Pi 4 units as local processing nodes and MCU30 modules for wireless transmission. This low-power wide-area network allows sensors to be placed far from the main Ground Station.

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Table 4.7: Ground Sensors Communications.

1	Raspberry Pi 4
2	Mobilicom communication modules MCU30
3	GroundSensorData Node possibly coincides with the Gateway module

D.MALIAN Meteorologial Station

This component is essential for providing localized accurate meteorological conditions context that is critical accurate disaster modeling. The main specifications of this very complete meteorological station is provided in Table 4.8.

Table 4.8: Main specifications of D.MALIAN meteorological station.

Model	Technical Specifications of the Meteorological Station
Sensor Recording and Data Transmission System:	MET.io Scientact AE
Compatibility	It has multiple analog, digital, and analog channels, making it compatible with almost any type of sensor or complex measuring system from any manufacturer.

• Enclosure It has a plastic or metal enclosure with an IP 67 protection rating.
• Pressure Equalization Valve: It has a pressure equalization valve.
• USB Port: It has a sealed external USB port for connection to a laptop.
• Battery Charging System: It has a battery charging system from a photovoltaic generator.
• Battery Capacity: The battery capacity is 7.5 AH.
• Modem: It has a modem compatible with LTE, NB-IoT, GPRS.
• Internal Antenna: It has an internal antenna.
• SIM Card: It has a SIM card compatible with all mobile networks. The system automatically selects the most suitable network.
• Recording Rate: It has a recording rate programmed every 5 minutes.
• Recording Rate Adjustment: The recording rate can be changed via USB and telemetry.
• Memory: It has an 8 GB SD card memory.
• Data Transmission: It has programmed data transmission every 15 minutes.
• Transmission Method: It has the ability to change the rate via USB and telemetry.
• File Format: The file format is CSV.
• Alarm Limits Programming: It has alarm limits programming via USB and telemetry.
• Alarm Transmission: Alarm transmission via email.
• Inputs:
  ○ Analog: 4
  ○ Digital: 2
  ○ SDI12	

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  - Modbus RTU
- Automatic Calculation: It automatically calculates statistical measures such as MIN, MAX, AVG.
- Temperature, Humidity, and Barometric Pressure Sensor: With a protective cage, Atmos 14 Meter Group.
- Protective Cage: It has a radiation shield.
- Output: SDI 12
- Operating Temperature: -40 to 80 °C
- Operating Voltage: At least in the range of 4 -15 V DC
- Maximum Consumption: During measurement 3.5mA
- Measurement Time: Typical measurement time 50ms.
- Simultaneous Measurement: It measures 4 meteorological parameters simultaneously.
- Relative Humidity:
  - Measurement Range: 0-100%
  - Measurement Resolution: 0.1%
- Air Temperature:
  - Measurement Range: -40 to 80 °C
  - Resolution: 0.1°C
  - Accuracy: ±0.20 °C
- Vapor Pressure:
  - Measurement Range: 0 to 47 kPa
  - Measurement Resolution: 0.01 kPa
- Barometric Pressure:
  - Measurement Range: 1-120 kPa
  - Resolution: 0.01 kPa
  - Accuracy: ±0.05 kPa
- Wind Speed Sensor Model: Small wind transmitter 4.3515.51.100 THIES CLIMA
  - Measurement Range: 0.9 – 40m/s
  - Sensor Output: 0-100Hz
  - Sensor Accuracy: ±0.5 m/s
  - Sensor Resolution: 0.4 m
  - Sensor Durability: max. 60 m/s
- Wind Direction Sensor Model: Small wind transmitter 4.3140.51.010 THIES CLIMA
  - Measurement Range: 10 ... 350 ° (20° dead zone in the north)
  - Type: Potentiometer
  - Ambient Temperature: -25 ... +60 °C, ice-free
  - Cable Length: 3 meters
  - Protection: IP54
  - Weight: 0.3 kg
- Rainfall Sensor Model: PROFESSIONAL PRONAMIC
  - Meteorologically predicted sensor according to WMO, tipping bucket type.

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  - The sensor is made of white UV protected plastic.
  - Sensitivity / Accuracy / Resolution: 0.2mm of rain per tipping.
  - Reset Mechanism: It has a magnet reset mechanism so that absolute leveling is not required.
  - Data Logger Compatibility: Suitable for connection to any data logger with pulse measurement capability.
  - Sensor Output: Pulses (1 pulse per 0.2mm of rain)
  - Collection Area: 200cm³
  - Reed Switches: It has two reed switches (one with NO and one with NC).
  - Measurement Accuracy: 2%
- Total Solar Radiation Sensor Model: LPPYRA-Lite SENSECA
  - Spectrally Flat Class C according to ISO 9060:2018
  - Sensor Element: Thermopile
  - Typical Sensitivity: 5-15μV/W/m²
  - Measurement Range: 0 – 2000 W/m²
  - Spectral Range (50%): 300 – 2800nm
  - Output: SDI12
  - Weight: 150g
  - Operating Temperature: -40 - 80°C
  - Protection Rating: IP 67
  - Response Time (95%): < 25s
- Meteorological Station Model: ATMOS 41 Gen 2 by METER America
  - Compact Station: No moving parts.
  - Digital Output: SDI 12 and modbus for data.
  - Typical Measurement Duration: 240 ms.
  - Water Conductivity Measurement: It can measure the electrical conductivity (EC) of water.
  - Rainfall Measurement Methods: It has two methods of measuring rainfall, a) drop counting with electrodes, b) tipping bucket.
  - Diameter: 10cm
  - Height: 28cm
  - Operating Voltage: 3.6 – 15 V DC
  - Typical Consumption: During measurement 8mA
  - Operating Temperature: -50 to +60°C
  - Compliance: Complies with EM ISO/IEC 17050:2010 (CE Mark).
- Solar Radiation:
  - Range: 0 to 1750 W/m²
  - Resolution: 1 W/m²
  - Accuracy: ± 5% of the measurement
- Rainfall:
  - Measurement Range: 0 to 1500 mm/h

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  - Resolution: 0.017 mm
  - Accuracy: ± 5% of the measurement in the range 0 to 1000 mm/h
- Vapor Pressure:
  - Range: 0 to 47 kPa
  - Resolution: 0.01 kPa
  - Accuracy at 20°C and in the humidity range 20-60% equal to or better than ±0.06 kPa
- Relative Humidity:
  - Range: 0 to 100%
  - Resolution: 0.1%
  - Accuracy at 20°C and in the range 0 – 100% equal to or better than 2%.
- Air Temperature:
  - Range: -50 to 60°C
  - Resolution: 0.1 °C
  - Sensor Accuracy: ± 0.2°C
- Barometric Pressure:
  - Range: 1 to 120 kPa
  - Resolution: 0.01 kPa
  - Accuracy: ± 0.05 kPa at 25°C
- Wind Speed:
  - Range: 0 to 60 m/s
  - Resolution: 0.01 m/s
  - Accuracy: the greater of 0.3 m/s or 3% of the measurement
- Wind Gust:
  - Range: 0 to 60 m/s
  - Resolution: 0.01 m/s
  - Accuracy: the greater of 0.3 m/s or 3% of the measurement
- Wind Direction:
  - Range: 0 to 359°
  - Resolution: 1°
  - Accuracy: ± 5°
- Mast Tilt – Installation:
  - Range: 0° to +180°
  - Resolution: 0.1°
  - Accuracy: ± 1°
- Lightning Count:
  - Range: 0 to 65,535 lightning strikes
  - Resolution: 1 lightning strike
- Lightning Detection Distance:
  - Range: 0 to 40 km
  - Resolution: 3 km

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- Snow Depth Sensor Model: USH-9 by SOMMER
    - Accurate snow depth measurement with ultrasonic sensor
    - Continuous non-contact measurement
    - Reverse Voltage Protection, Surge Protection
    - Built-in Temperature Compensation
    - Lightning Protection
    - Operating Voltage: 10.5 – 15 V DC
    - Operating Temperature: -40 ... 60 °C
    - Anodized Aluminum Housing
    - Weight: 1.2 kg
    - Protection: IP 64
    - Measurement Range: 0.7 – 10m
    - Accuracy: 0.1% of full scale
    - Temperature Sensor: It has a temperature sensor in a naturally ventilated housing
    - Temperature Measurement Range: -40 ... 60 °C
    - Temperature Measurement Resolution: 0.01 °C
    - Temperature Measurement Accuracy: 0.3 °C
    - Outputs: RS-485 ASCII / Modbus RTU, SDI-12, 2xAnalog outputs 4...20 mA
    - Provided Measurements: Snow height, air temperature

4.3.7 DLR-KN Ground Station

The DLR-KN Ground Station serves as the primary mobile command and communication hub for the TEMA operational area. This system is implemented as a specialized command van, offering both a reliable workspace and critical infrastructure for network connectivity and sensor integration. As the central point of the edge network, the DLR-KN ground station is responsible for bridging local, high-bandwidth communications. The physical setup, shown in Figure 9, is highly mobile and designed for rapid deployment in disaster zones. The most critical function of the DLR-KN station is providing robust internet backhaul for the entire edge network. The details are shown in Table 4.9.

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Figure 12: DLR-KN Ground Station. This image shows the mobile command van during field operations, highlighting its deployment capability and dedicated workspace.

Table 4.9: DLR-KN Ground Station Technical Specifications.

Work Space	- Two seats in the van - Camping chairs/Tables for more
Mounting Capability	Roof Platform capable of mounting communications technology
Communication	- Starlink Regional Module - 4G/5G Connectivity with Netgear Module - Mobilicom MCU30 modules connected to Ground Sensor Network and sensors
Power	- Built-in Batteries, 12/24V DC, 230V AC - Maximum Capacity 5000W

4.3.8 TEMA Edge Nodes

This section summarizes the hardware description of the main edge nodes of the TEMA platform. Each component includes: the technology it is linked with, the responsible partner, and main characteristics. The description also includes the number of persons and power sockets for each component, as this information is crucial for the planning and logistics of the trials.

EDGE1-USE

Table 4.10: Characteristics of EDGE1-USE computer.

TEMA functionality	SV-tech-01, drone images, and data acquisition

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Responsible	USE
Computer model	Laptop ASUS Vivobook 16 F1605VA Intel Core i7-1355U/16GB/1TB SSD/16''
Size	36 x 23.5 x 2 cm
Weight	1.9 kg
Power Consumption	- Power Adapter: 65W AC adapter. - Battery: 3-cell Li-ion battery. - Battery Life: Up to 8 hours, depending on usage
Interfaces	USB-C, USB-A, HDMI, 3.5mm audio jack, Wi-Fi 6, Bluetooth 5.2
Minimum Number of Persons	1
Number of Sockets	1 (Power adapter)

EDGE2-AUTH

Table 4.11: Characteristics of EDGE2-AUTH computer.

TEMA functionalities	TFA-tech-05, fire/smoke/person detection TFA-tech-06, fire/flood/background segmentation
Responsible	AUTH
Computer model	ASUS G701V
Size	43 x 31 x 3 cm
Weight	3.8 Kg
Power Consumption	- Laptop Power Consumption: 330 W (347 Wh) - Battery Life: (Defect, up to 30 mins)
Interfaces	USB-C (Thunderbolt 3), USB-A, HDMI, Ethernet, Wi-Fi 6, Bluetooth 5.0, SD card reader
Minimum Number of Persons	1
Number of Sockets	1 (Power adapter)

EDGE3-ATOS

Table 4.12: Characteristics of EDGE3-ATOS computer.

TEMA functionality	TFA-tech-07, Person re-identification
Responsible	ATOS
Computer model	Lenovo ThinkPad T15g
Size	37.5 x 25 x 3
Weight	2.74 kg
Power Consumption	-Laptop Power: 230W - Battery: with issues requires a power supply
Interfaces	USB-C (Thunderbolt 3), USB-A, HDMI, Ethernet, Wi-Fi 6, Bluetooth 5.2, SD card reader
Minimum Number of Persons	1
Number of Sockets	1 (Power adapter)

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EDGE4-ND

Table 4.13: Characteristics of EDGE4-ND visualization system.

TEMA functionality	SV-tech-06, Extended Reality-based interactive visualization system
Responsible	ND
Computer model	VR Headset Pico4Ultra
Size	300mm x 165mm x 84mm
Weight	1 kg
Power Consumption	12W
Interfaces	Wlan
Minimum Number of Persons	1
Number of Sockets	1 USB-C

EDGE6-DLR-KN

Table 4.14: Characteristics of EDGE6-DLR-KN computer.

TEMA functionality	PDM-tech03, Realistic 3D smoke modelling and fire detection
Responsible	DLR-KN
Computer model	Laptop Dell Precision 6100
Size	Laptop + Raspberry pi
Weight	5kg
Power Consumption	180W
Interfaces	Thunderbolt, usb-C, usbA, ethernet
Minimum Number of Persons	1
Number of Sockets	Power sockets? 1

EDGE7-UNIME

Table 4.15: Characteristics of EDGE7-UNIME computing system.

TEMA functionality	TFA-tech-14, Federated Learning
Responsible	UNIME
Hardware	2 Raspberry Pi 4 devices
VM Configuration	Quad-core ARM Cortex-A72 CPU and 4 GB RAM
Interfaces	Wired Ethernet

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4.3.9 TEMA Cloud Nodes

The TEMA Cloud Nodes constitute the centralized, high-performance computational core of the platform. These nodes host the sophisticated partner technologies that transform multi-source data into strategic intelligence for emergency management. A foundational element for this cloud layer is the Core Integration Platform (CLOUD1-ENG), which provides the central event broker (Orion Context Broker) and object storage (MinIO) that enable all other components to interoperate seamlessly using the NGSI-LD API and data model. This cloud portfolio is dedicated to resource-intensive processing, operating on data ingested via this unified communication layer.

CLOUD1-ENG

Table 4.16: Characteristics of CLOUD1-ENG.

TEMA functionality	[SV-tech-02] Digital Enabler: A native cloud platform for discovering, integrating, and harmonizing multi-source data. It uses NGSI-LD/FIWARE APIs.
Responsible	ENG
Interfaces	Primary Interface for ALL Components: NGSI-LD API (REST/HTTP/JSON-LD). This is the standard protocol for publishing and subscribing to context information. Additional Interfaces: S3 API (for MinIO), MQTT, CoAP, OPC-UA (for data ingestion adapters).

CLOUD2-UNIME

Table 4.17: Characteristics of CLOUD2-UNIME.

TEMA functionality	[TFA-tech-14] Federated Learning: A framework for privacy-preserving distributed AI model training. It aggregates model weights from edge devices to create and distribute a global model.
Responsible	UNIME
Hardware	Server hosting 4 virtual machines
VM Configuration	4 vCPUs and 16 GB RAM
Interfaces	Primary: NGSI-LD API (HTTP/REST) for model weight aggregation and distribution. Object Storage:S3-compatible REST API (for MinIO). Secondary: Wired Ethernet for internal cluster communication.

CLOUD3-ND

Table 4.18: Characteristics of CLOUD3-ND.

TEMA functionality	[SV-tech-03] 3D Computer Vision/Photogrammetry: Generates precise, real-time Digital Twins from heterogeneous visual data using [SV-tech-06] Extended Reality (XR) Visualization: An interactive XR application for visualizing operational data for command and control.

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Responsible	ND
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD4-LAT40

Table 4.19: Characteristics of CLOUD4-LAT40.

TEMA functionality	[SV-tech-04] Geovisual Analytics: A cluster computing system for interactive analytical reasoning with large-scale geospatial data. Uses in-memory processing for high-speed visualization.
Responsible	LAT40
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD5-KAMK

Table 4.20: Characteristics of CLOUD5-KAMK.

TEMA functionality	[SV-tech-07] Smartdesk Application: A touchscreen-embedded command center for visualizing data and directing on-site personnel.
Responsible	KAMK
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD6-DLR-DFD

Table 4.21: Characteristics of CLOUD6-DLR-DFD.

TEMA functionality	[TFA-tech-08] Satellite-based Flood Detection: ML processor for Sentinel-1/2 for flood monitoring and assessment. [TFA-tech-09] Satellite-based Forest Fire Detection: DNN processor for Sentinel-3/MODIS for NRT burnt area monitoring.
Responsible	DLR-DFD
Interfaces	Data Output: OGC Web Services (WMS, WFS) for map layers, SpatioTemporal Asset Catalog (STAC) API, and GeoPackage (GPKG) file delivery. (Needs Gateway to interact with TEMA platform, as this technology runs on DLR-DFD servers.)

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CLOUD7-PLUS

Table 4.22: Characteristics of CLOUD7-PLUS.

TEMA functionality	[TFA-tech-11] Geo-social Media Analysis: Analyzes georeferenced social media posts for situational awareness, hotspot detection, and sentiment analysis.
Responsible	PLUS
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD8-ATOS/AUTH

Table 4.23: Characteristics of CLOUD8-ATOS/AUTH.

TEMA functionality	[TFA-tech-13] Contrastive Image-Language Models: Uses models like CLIP to analyze semantic coherence in social media posts (image-text pairs) to validate disaster reports.
Responsible	ATOS/PLUS
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD9-TSYL

Table 4.24: Characteristics of CLOUD9-TSYL.

TEMA functionality	[PDM-tech-01] Forest Fire Simulation: Uses Wildfire Analyst FireSim for real-time wildfire behavior analysis and spread simulation.
Responsible	TSYL
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO). (Needs Gateway to interact with TEMA platform as this technology runs on TYSL servers.)

CLOUD10-NS

Table 4.25: Characteristics of CLOUD10-NS.

TEMA functionality	[PDM-tech-02] 3Di Hydrodynamic Simulation: A physics-based model for simulating water behavior in rural and urban areas, supporting interactive scenarios.
Responsible	NS
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO). (This technology runs on NS servers.)

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CLOUD11-USE

Table 4.26: Characteristics of CLOUD11-USE.

TEMA functionality	[PDM-tech-04] Drone Planning: Automated planning engine for optimal dynamic UAV placement.
Responsible	USE
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD12-USE

Table 4.27: Characteristics of CLOUD12-USE.

TEMA functionality	[PDM-tech-05] Information Fusion: Engine for optimal event status estimation using georeferenced Bayesian Filtering
Responsible	USE
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD13-DLR-DFD

Table 4.28: Characteristics of CLOUD13-DLR-DFD.

TEMA functionality	[PDM-tech-06] Data-fusion-based Decision Support: Automates disaster AOI detection and satellite tasking by fusing alerts, simulations, and satellite acquisition plans.
Responsible	DLR-DFD
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

CLOUD14-FHHI

Table 4.29: Characteristics of CLOUD14-FHHI.

TEMA functionality	[TFA-tech-02] Human-comprehensible Presentation of Concept-based Explanations: Develops interpretable explanation formats for AI model decisions to make them actionable for end-users.
Responsible	FHHI
Interfaces	NGSI-LD API (HTTP/REST). Object Storage:S3-compatible REST API (for MinIO).

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5 Preparation of the trials

To prepare for the trials, a series of preliminary activities were carried out to verify the data provided by the pilots, define the scenarios and test the platform in advance. In this section, we will report on the tools and organisation adopted to manage communication and testing of the platform.

5.1 Communication and managing Tools

Effective communication and the use of appropriate management tools are critical to the successful preparation and execution of trials. This section outlines the platforms, protocols, and coordination mechanisms employed to ensure seamless collaboration among stakeholders & programmers, timely information exchange, and efficient oversight throughout the trial process.

5.1.1 Integration Issue Management

The TEMA project made extensive use of a private GitHub repository (Figure 10), provided and maintained by the University of Messina (UNIME), with the aim of systematically and traceably managing all activities related to the integration process between the various software components developed within the project. In particular, the section dedicated to repository issues (available only for authorized partners at the following address: https://github.com/HE-TEMA/SW-integration/issues) was a key reference point for the collaborative management of bugs, change requests, verification and alignment activities between modules, as well as for monitoring the progress of individual reports. Each issue was appropriately classified, assigned and followed up in accordance with agile development best practices, facilitating full traceability of issues and corrective actions taken. This approach enabled the consortium to maintain a high level of coordination between the technical partners involved in development and integration activities, ensuring progressive convergence towards a unified, stable and interoperable architecture for the TEMA platform. The use of the GitHub repository has therefore proved to be a crucial tool for the adoption of a rigorous, transparent and collaborative working methodology.

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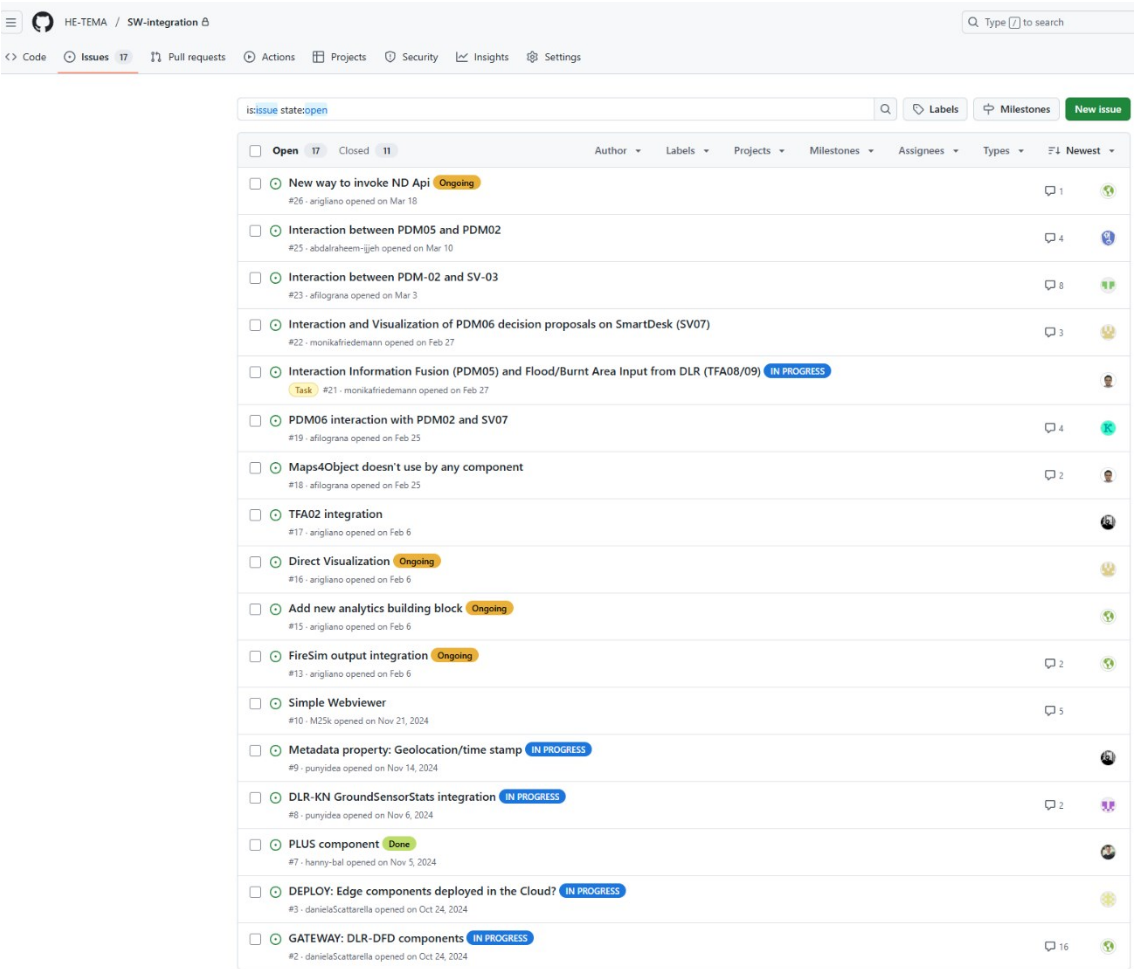

Figure 13: GitHub for issue management

5.1.2 Developer activities coordination

In the context of the TEMA project, in order to ensure effective, timely and structured communication between the partners involved in software development and infrastructure management activities, the Slack platform was adopted as the central tool for daily operational collaboration. In particular, Slack proved extremely useful for coordinating the activities of the development teams, enabling a continuous exchange of updates, code, technical documentation and bug reports between the various working groups, even those distributed geographically. Through dedicated thematic channels, it was also possible to manage system-related requests, such as environmental configurations, cloud resource provisioning, container management and microservice deployment, in an agile and efficient manner (Figure 14).

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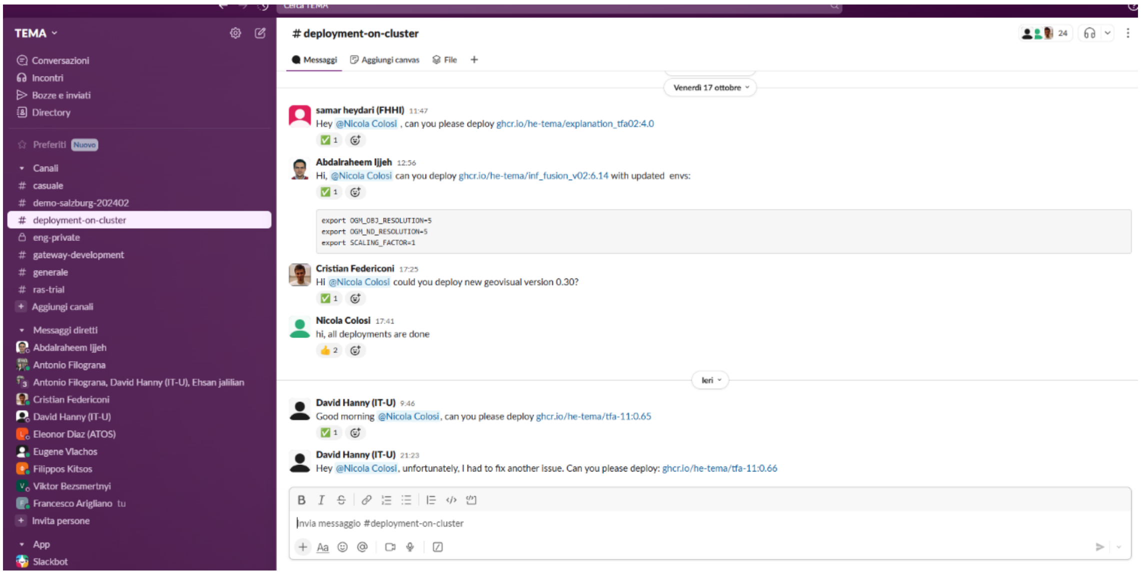

Figure 14: Deployment management channel

Furthermore, Slack played a key role in the integration testing phase between the TEMA platform modules, facilitating the tracking of activities, the sharing of test results, the rapid identification and resolution of emerging issues, and promoting cross-functional collaboration between technical partners (Figure 15). The constant use of Slack has therefore contributed significantly to improving the operational cohesion of the consortium and supporting the adoption of agile and iterative methodologies during the development of the platform.

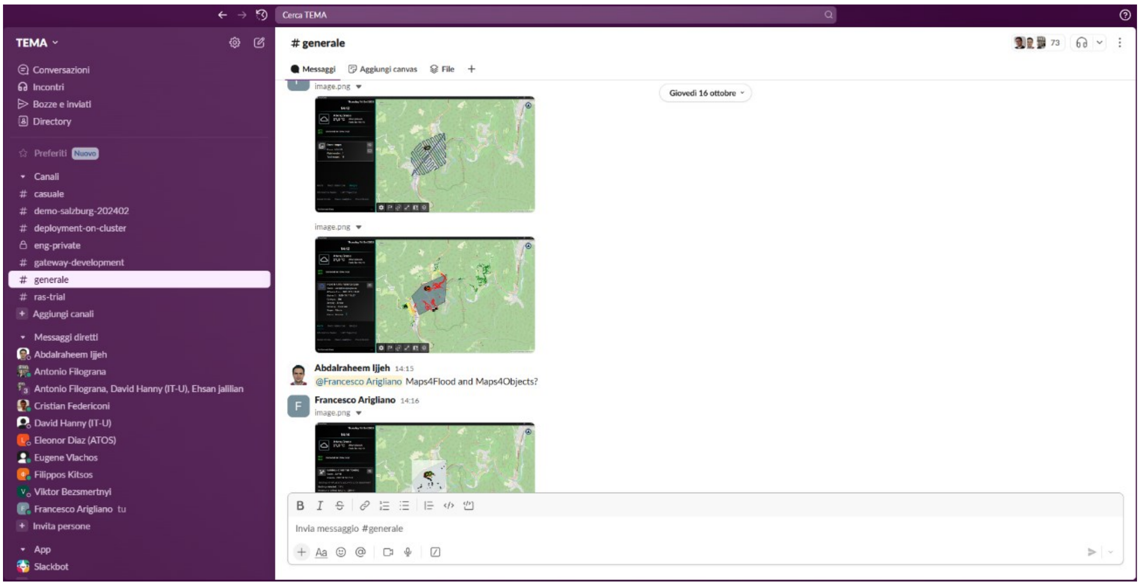

Figure 15: General channel for integration testing coordination

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5.2 Testing

Integration testing was a crucial phase in the development lifecycle of the TEMA platform, as it was designed to ensure that the various software modules – developed in a distributed manner by multiple technology partners – could interoperate in a consistent, stable and reliable manner within the overall architecture. Integration testing was conducted iteratively and incrementally, following a bottom-up approach, which allowed for the progressive validation of interactions between software components, services, APIs, data flows and orchestration mechanisms. These activities were facilitated by a shared continuous integration environment, within which the various modules were integrated, configured and tested according to scenarios representative of real use cases.

The integration methodology adopts the **Plugfest**[1] approach, a well-established industrial practice for validating interoperability in distributed systems and IoT ecosystems. Formalized in the European context by standard-setting organizations such as ETSI, this approach allows multiple vendors to connect their implementations in a shared environment to pragmatically test syntactic and semantic API compatibility (e.g., NGSI-LD interfaces).

Particular attention was paid to verifying the semantic and syntactic compatibility between microservice interfaces, the integrity of data exchanged via the NGSI-LD-based Context Broker, and the correct functioning of processing pipelines, from data collection (edge/cloud) to visualisation. During this phase, functional tests, regression tests, and end-to-end tests were performed under controlled conditions, but with the data that is representative of operational scenarios (e.g., fire or flood historical data). All anomalies, discrepancies, or unexpected behaviours observed during testing were managed through the issue tracking system on the dedicated GitHub repository, allowing for rapid identification, assignment, and resolution of problems. Overall, integration testing activities played a key role in consolidating the robustness of the TEMA ecosystem, facilitating the early detection of any critical issues and contributing significantly to the construction of a coherent, interoperable platform ready for testing in pilot contexts.

5.2.1 Testing Activities organization

The diagram in the Figure 13 and the subsequent summary description illustrate the strategy used during the project for component and integration and testing in an iterative way.

[1] https://calhoun.nps.edu/bitstreams/5f821eb5-68b2-4ef1-8ef1-db97efd95882/download

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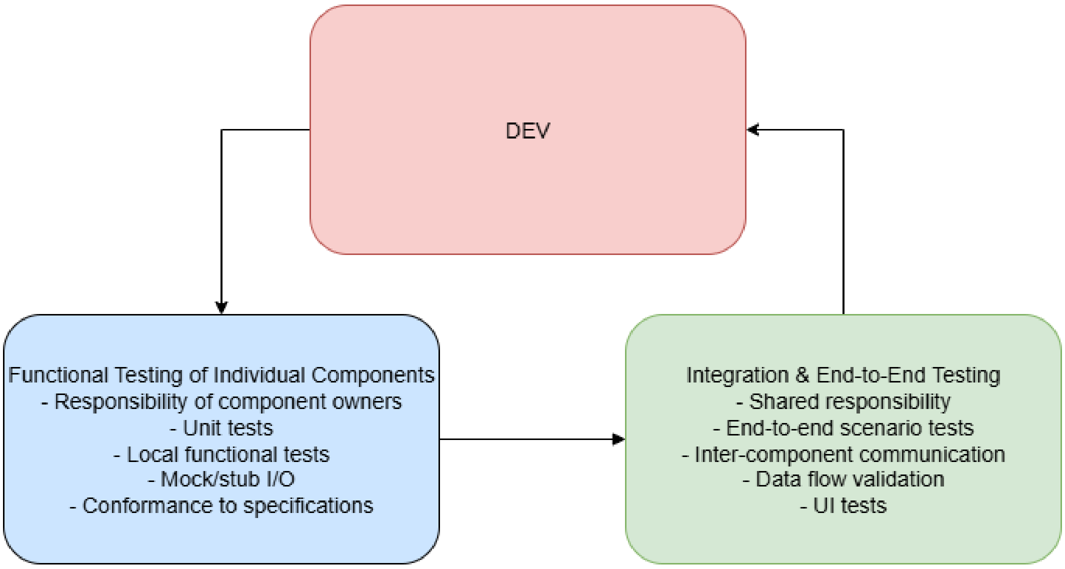

Figure 16: TEMA testing approach

Functional testing of individual components

Responsibility: assigned to component owners (i.e., partners responsible for developing individual modules).

Activities included:

- Unit testing
- Local functional testing
- Input/output mock/stubs
- Verification of compliance with defined functional specifications

Objective: to ensure that each component is independently stable and compliant before being integrated.

Integration testing and end-to-end testing

Responsibility: shared among the technical partners involved in the integration.

Environment: orchestrated on shared TEMA infrastructure (e.g. containerised environment + common storage and Context Broker with REST/NGSI-LD interfaces).

Activities included:

- End-to-end testing according to real scenarios (e.g. flood or fire events)
- Verification of communication between components

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- Validation of data flows along the entire business mission (data → processing → visualisation)
- Testing of user interfaces (Dashboard, SmartDesk, XR)

Objective: to verify that the entire system cooperates as expected and that data and services are interoperable throughout the chain.

Dev

Problems and new requirements generated during testing are placed in the development backlog for individual components, and after functional testing of releases, the cycle repeats.

Roles and Responsibilities

To ensure accountability, testing responsibilities are clearly distributed among the consortium partners based on their technical roles:

Role	**Responsible Partner(s)**	**Key Responsibilities**
Component Owners	All	Unit testing, local functional testing, input/output mocks/stubs, and verifying compliance with component specifications.
Integration Lead	ENG/UNIME	Orchestrating the shared TEMA infrastructure, managing the CI/CD pipelines, and verifying NGSI-LD semantic/syntactic compatibility, running the plugfest sessions.
End-to-End Testers	All	Executing full business-mission flows (data → processing → visualization), UI testing (Dashboard, SmartDesk, XR), and validating real-world scenarios.
QA& Reporting	ENG	Overseeing the issue tracking process, defining passing criteria, and compiling test reports.

Testing Timeline and Execution Strategy

The testing process follows an iterative, bottom-up approach aligned with the project's main release cycles. Testing is not a single event, but a continuous process divided into specific phases:

1. Continuous Component Testing (M[12] – M[36]): each component owner tests its own technology upon every new code update. This ensures baseline stability.

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2. Integration Plugfest Sessions (M[19], M[36]): Dedicated bi-weekly integration sprints, where TEMA modules are deployed on the shared TEMA infrastructure (containerized environment with the NGSI-LD Context Broker). They are coordinated by the Integration lead (ENG/UNIME).
3. Pre-Pilot End-to-End Testing (30 days before the pilots trial execution): It is performed strictly before the pilot trial execution. Functional, regression, and end-to-end tests are performed under controlled conditions using historical data representative of operational scenarios (e.g., fire or flood historical datasets). It is coordinated by the Integration Lead, in cooperation with the pilot trial partner and KEMEA.
4. Pilot trial testing: End-to-end tests to be reported in Deliverable D6.4. It will contain both end user evaluation using related questionnaire and technical evaluation of several TEMA technologies on pilot trial data. It is coordinated by the Integration Lead, in cooperation with the pilot trial partner and KEMEA.

Details on TEMA platform testing will be included in Deliverable D6.3 and D6.4.

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6 Use Case Integration

The following section delineates the integration of TEMA components and services within selected pilot use cases, as operationalized and evaluated through real-world or simulated field deployments. The primary objective consists in demonstrating the practical applicability, interoperability, and technological maturity of the TEMA platform in addressing specific Natural Disaster Management (NDM) scenarios across diverse operational contexts.

Each subsection examines a distinct pilot scenario, elucidating the manner in which the constituent technological building blocks, encompassing AI modules, data processing pipelines, edge-cloud infrastructure, and SmartDesk interfaces, have been integrated and validated under realistic operational conditions.

6.1 Scenario 1: Ahrtal Flood Historical

In the next sub paragraphs the key information about the Ahrtal historical trial execution are summarized and explained in more detail.

6.1.1 Ahrtal trial tested component

The following table shows which TEMA technologies were used to conduct the trial. Some of them are indicated as research only; in these cases, the technologies developed were not used in the trials.

Table 6.1: Report on tested component during BRK trial

ID	Component	Owner	Used
TFA-tech-01	Concept discovery for latent space interpretability of deep neural networks	FHHI	only Research
TFA-tech-02	Human-comprehensible presentation of concept-based explanations	FHHI	yes
TFA-tech-03	DNN robustness	AUTH	only Research
TFA-tech-04	Explainability for transformer base neural networks	ATOS	yes

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TFA-tech-05	Fire/smoke/person detection	AUTH	yes
TFA-tech-06	Fire/flood/background segmentation	AUTH	yes
TFA-tech-07	Person re-identification	ATOS	yes
TFA-tech-08	Satellite-based flood detection and assessment	DLR-DFD	yes
TFA-tech-09	Satellite-based Forest fire detection and assessment	DLR-DFD	N/A
TFA-tech-10	Privacy preservation during visual analysis	AUTH	no
TFA-tech-11	Geo-social media analysis	PLUS	yes
TFA-tech-12	Sentiment analysis for short texts	AUTH	only Research
TFA-tech-13	Contrastive image-language models	ATOS	yes
TFA-tech-14	Federated Learning	UNIME	only Research
TFA-tech-15	Data scarcity, synthetic data generation pipeline	ATOS	yes
PDM-tech-01	Forest Fire Simulation	TSYL	N/A
PDM-tech-02	3Di Hydrodynamic simulation	NS	yes

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PDM-tech-03	Realistic 3D smoke modelling and fire detection	DLR-KN	N/A
PDM-tech-04	Drone planning	USE	yes
PDM-tech-05	Information fusion	USE	yes
PDM-tech-06	Data-fusion-based decision support and process triggering	DLR-DFD	yes
SV-tech-01	Drone-based image and data acquisition	USE	yes
SV-tech-02	Digital Enabler	ENG	yes
SV-tech-03	3D computer vision (SfM)/ Photogrammetry	Northdocks	yes
SV-tech-04	Geovisual Analytics	LAT40	yes
SV-tech-05	Geospatial information retrieval	AUTH	only Research
SV-tech-06	Extended Reality-based interactive visualisation system	Northdocks	yes
SV-tech-07	Smartdesk Application	KAMK	yes

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6.1.2 Ahrtal trial Business mission

In the Ahrtal trial we tested the entire general flow diagram, as already shown in Figure 4.

6.1.3 Screenshots from the trial execution

In this section, we show some selected screenshots taken from SmartDesk during the trial run. Not all the features tested are shown below. Our goal is to simply provide an overview together with the screenshots in the corresponding sections of the other trials. For details about the functionalities of Smartdesk refer to TEMA deliverable D5.3.

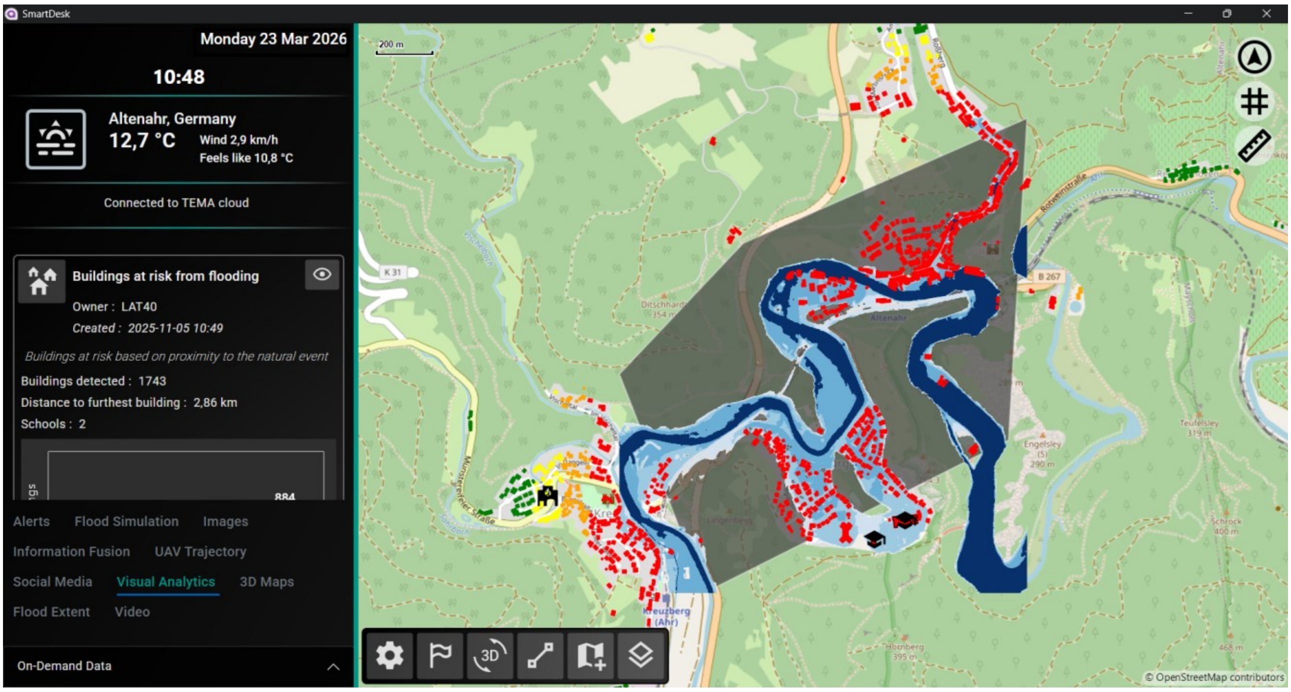

Figure 17: flood simulation with distance from building decision support

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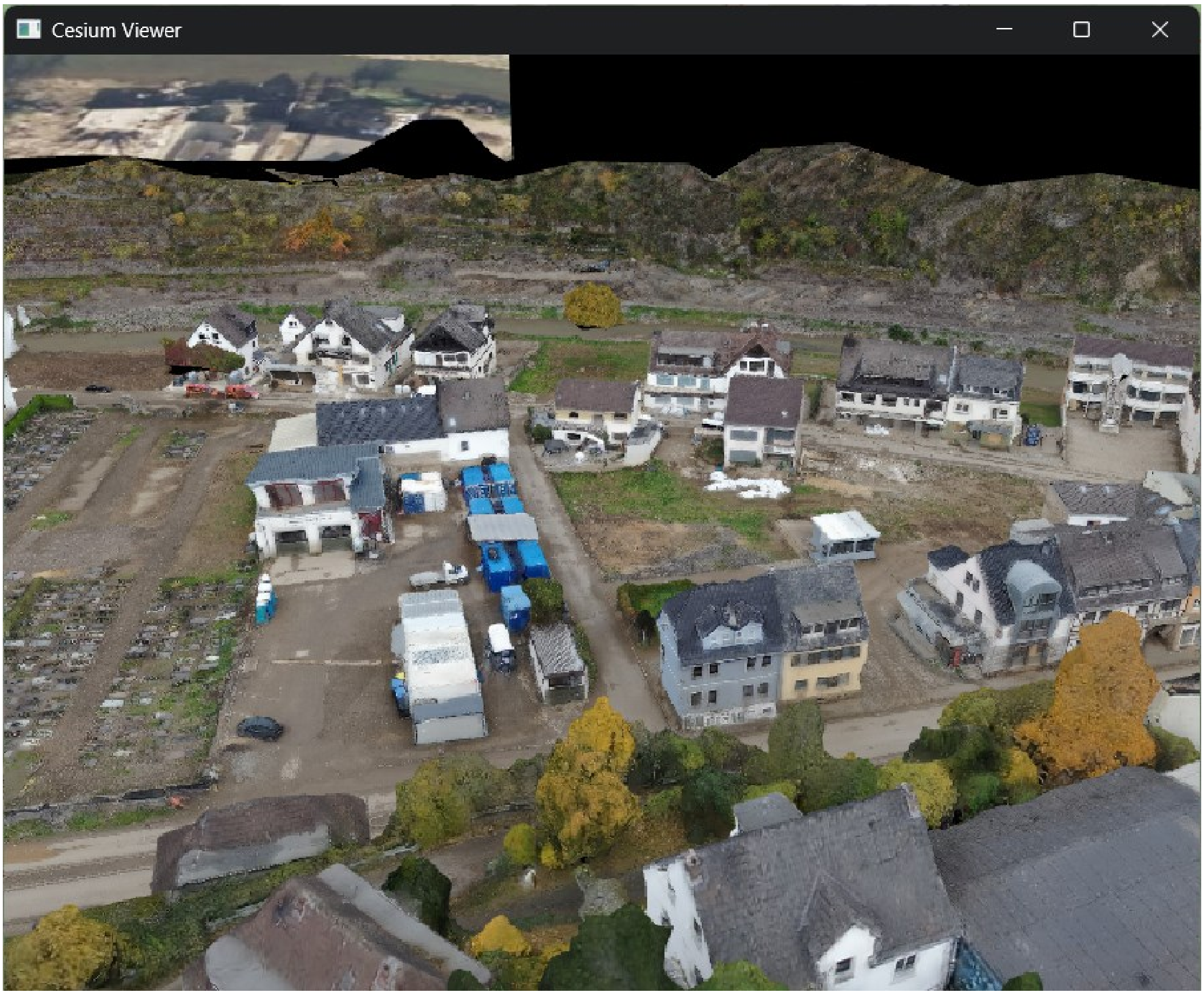

Figure 18: 3D model generated from drone images in real time

6.2 Scenario 2: RAS Forest Fires (RT)

In the next sub paragraphs the key information about the RAS trial execution

6.2.1 RAS trial tested component

The following table shows which TEMA technologies were used to conduct the trial. Some of them are indicated as research only; in these cases, the technologies developed were not used in the trials.

Table 6.2: Report on tested component during RAS trial

ID	Component	Owner	Used

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TFA-tech-01	Concept discovery for latent space interpretability of deep neural networks	FHHI	only Research
TFA-tech-02	Human-comprehensible presentation of concept-based explanations	FHHI	no
TFA-tech-03	DNN robustness	AUTH	only Research
TFA-tech-04	Explainability for transformer base neural networks	ATOS	no
TFA-tech-05	Fire/smoke/person detection	AUTH	yes
TFA-tech-06	Fire/flood/background segmentation	AUTH	yes
TFA-tech-07	Person re-identification	ATOS	no
TFA-tech-08	Satellite-based flood detection and assessment	DLR-DFD	no
TFA-tech-09	Satellite-based Forest fire detection and assessment	DLR-DFD	no
TFA-tech-10	Privacy preservation during visual analysis	AUTH	no
TFA-tech-11	Geo-social media analysis	PLUS	yes
TFA-tech-12	Sentiment analysis for short texts	AUTH	Only Research
TFA-tech-13	Contrastive image-language models	ATOS	no
TFA-tech-14	Federated Learning	UNIME	only Research
TFA-tech-15	Data scarcity, synthetic data generation pipeline	ATOS	no
PDM-tech-01	Forest Fire Simulation	TSYL	yes
PDM-tech-02	3Di Hydrodynamic simulation	NS	no
PDM-tech-03	Realistic 3D smoke modelling and fire detection	DLR-KN	yes

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PDM-tech-04	Drone planning	USE	yes
PDM-tech-05	Information fusion	USE	yes
PDM-tech-06	Data-fusion-based decision support and process triggering	DLR-DFD	yes
SV-tech-01	Drone-based image and data acquisition	USE	yes
SV-tech-02	Digital Enabler	ENG	yes
SV-tech-03	3D computer vision (SfM)/ Photogrammetry	Northdocks	yes
SV-tech-04	Geovisual Analytics	LAT40	yes
SV-tech-05	Geospatial information retrieval	AUTH	Only research
SV-tech-06	Extended Reality-based interactive visualisation system	Northdocks	no
SV-tech-07	Smartdesk Application	KAMK	yes

6.2.2 RAS trial Business mission

Below we will show the diagram of the business mission that was tested during the trial. In particular, during the real-time RAS trial, the network of sensors in the field was tested, which had never been tested before.

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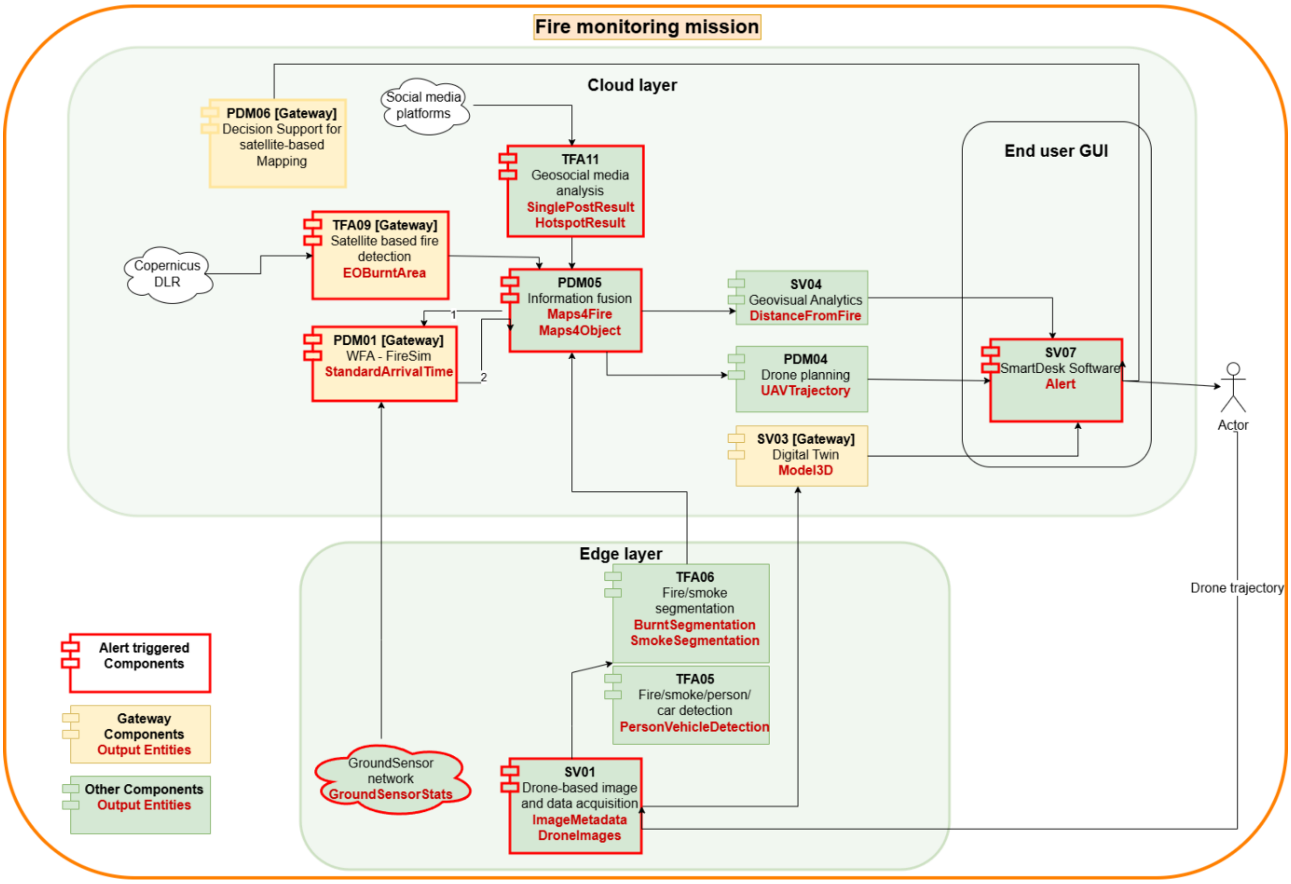

Figure 19: Business mission tested during the trial

6.2.3 Screenshots from the trial execution

In this section, we show some selected screenshots taken from SmartDesk during the trial run. Not all the features tested are shown below. Our goal is to simply provide an overview together with the screenshots in the corresponding sections of the other trials. For details about the functionalities of Smartdesk refer to TEMA deliverable D5.3.

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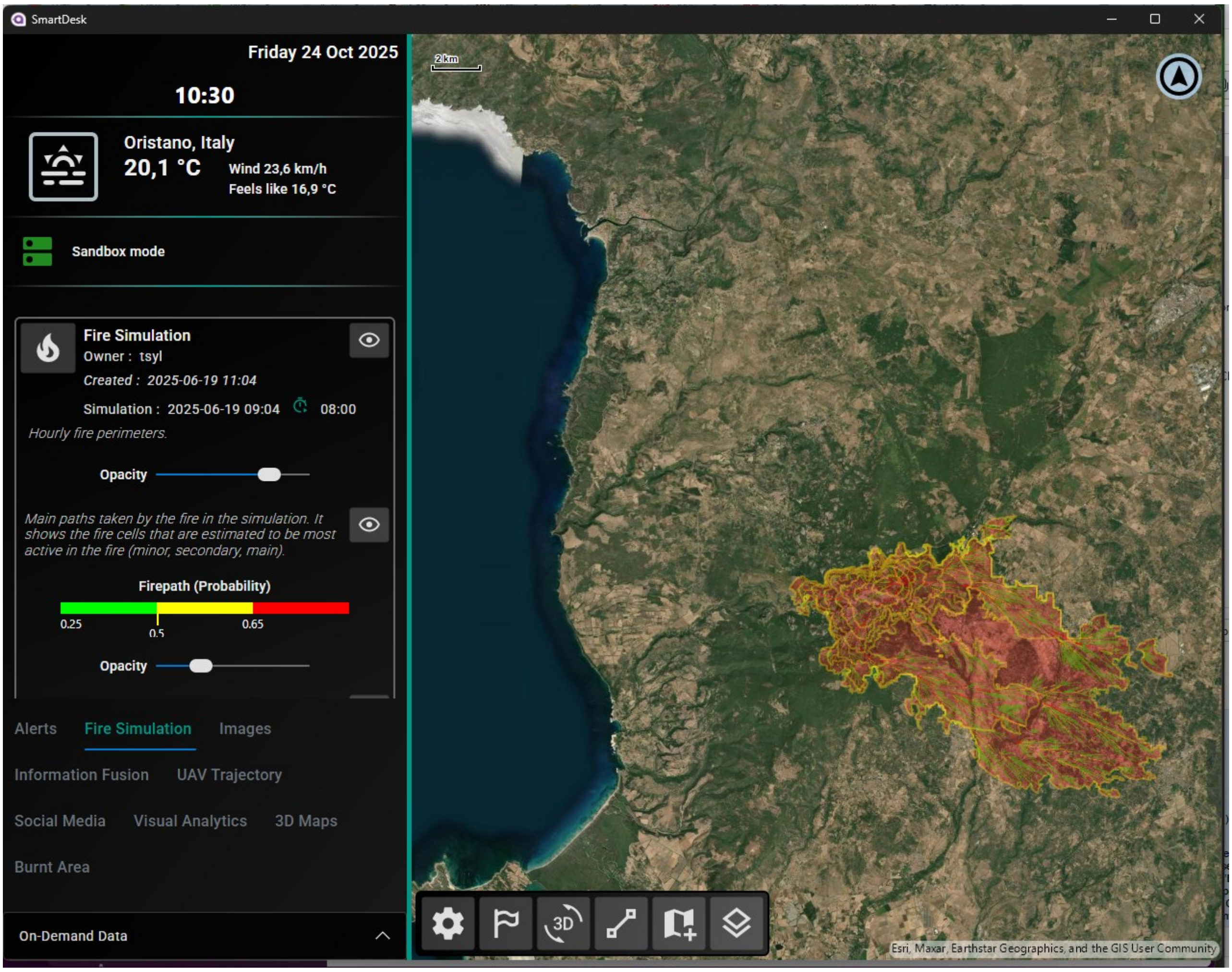

Figure 20: RAS trial fire simulation view on Smartdesk

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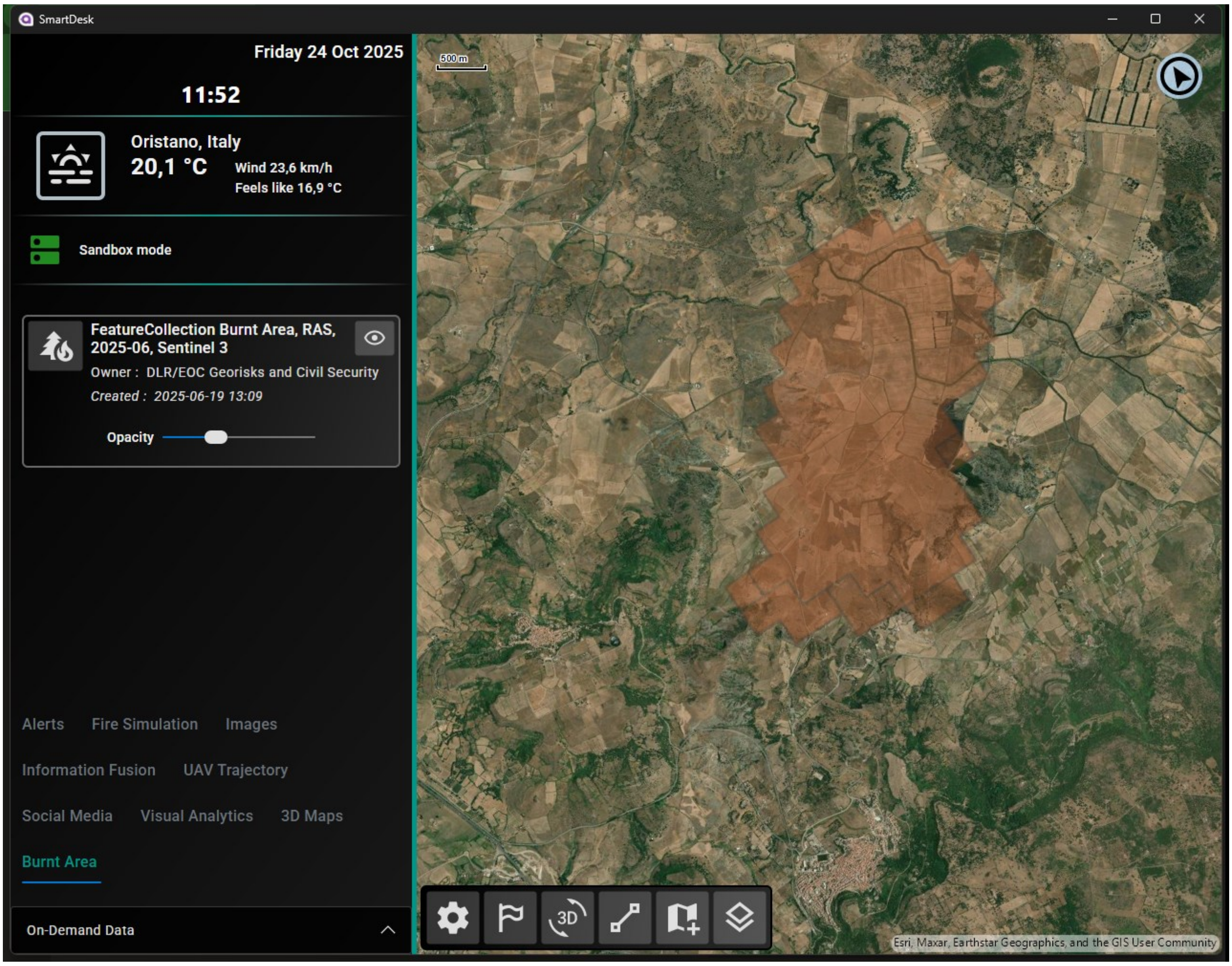

Figure 21: Satellite based burnt area analysis

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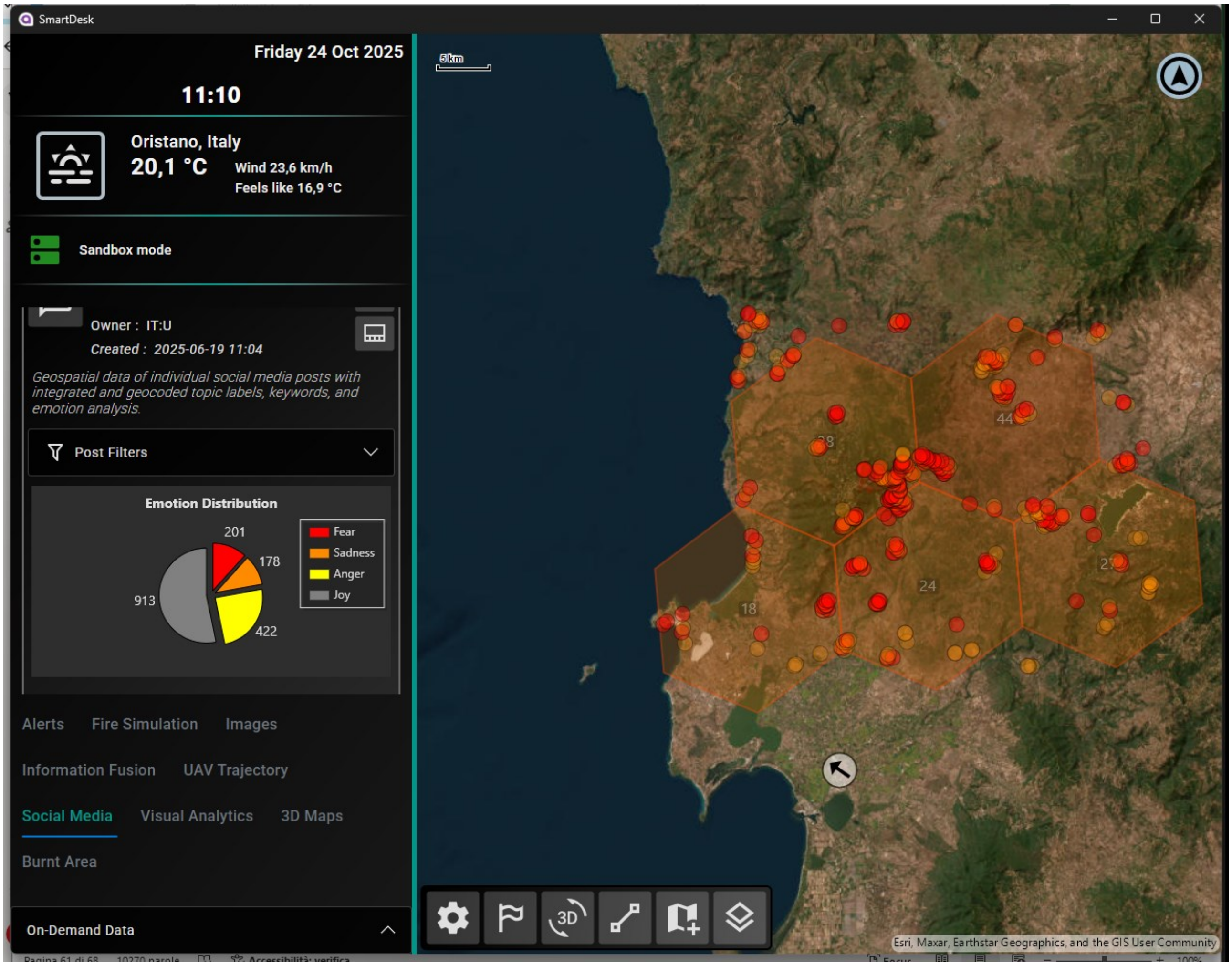

Figure 22: Geo social media analysis view during the trial

6.3 Scenario 3: D. MALIAN Floods

6.3.1 This section focuses on the D.MALIAN flood historical trial. D.MALIAN trial tested component

The following table shows which TEMA technologies were used to conduct the trial. Some of them are indicated as research only; in these cases, the technologies developed were not used in the trials.

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Table 6.3: report on tested component during D.MALIAN trial

ID	Component	Owner	Used ?
TFA-tech-01	Concept discovery for latent space interpretability of deep neural networks	FHHI	only Research
TFA-tech-02	Human-comprehensible presentation of concept-based explanations	FHHI	yes
TFA-tech-03	DNN robustness	AUTH	only Research
TFA-tech-04	Explainability for transformer base neural networks	ATOS	no
TFA-tech-05	Fire/smoke/person detection	AUTH	yes
TFA-tech-06	Fire/flood/background segmentation	AUTH	yes
TFA-tech-07	Person re-identification	ATOS	no
TFA-tech-08	Satellite-based flood detection and assessment	DLR-DFD	yes
TFA-tech-09	Satellite-based Forest fire detection and assessment	DLR-DFD	no
TFA-tech-10	Privacy preservation during visual analysis	AUTH	
TFA-tech-11	Geo-social media analysis	IT:U	yes
TFA-tech-12	Sentiment analysis for short texts	AUTH	only Research
TFA-tech-13	Contrastive image-language models	ATOS	yes
TFA-tech-14	Federated Learning	UNIME	only Research
TFA-tech-15	Data scarcity, synthetic data generation pipeline	ATOS	no
PDM-tech-01	Forest Fire Simulation	TSYL	no

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PDM-tech-02	3Di Hydrodynamic simulation	NS	yes
PDM-tech-03	Realistic 3D smoke modelling and fire detection	DLR-KN	no
PDM-tech-04	Drone planning	USE	yes
PDM-tech-05	Information fusion	USE	yes
PDM-tech-06	Data-fusion-based decision support and process triggering	DLR-DFD	no
SV-tech-01	Drone-based image and data acquisition	USE	yes
SV-tech-02	Digital Enabler	ENG	yes
SV-tech-03	3D computer vision (SfM)/ Photogrammetry	ND	yes
SV-tech-04	Geovisual Analytics	LAT40	yes
SV-tech-05	Geospatial information retrieval	AUTH	no
SV-tech-06	Extended Reality-based interactive visualisation system	ND	no
SV-tech-07	Smartdesk Application	KAMK	yes

6.3.2 D.MALIAN trial Business mission

Below we will show the diagram of the business mission that was tested during the trial.

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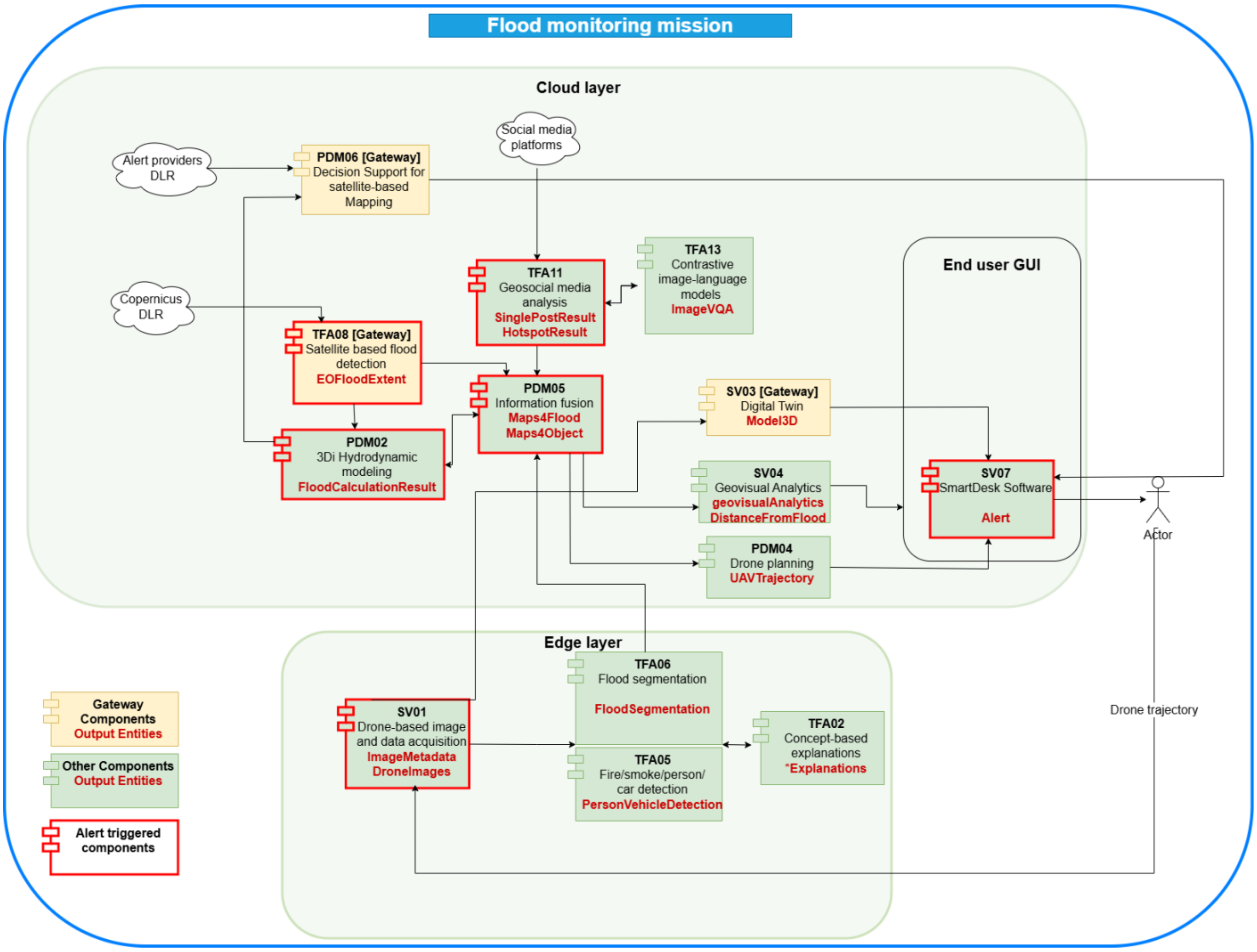

Figure 23: business mission tested during the trial

6.3.3 Screenshots from the trial execution

In this section, we show some screenshots taken from SmartDesk during the trial run. Not all the features tested will be covered; the aim is simply to provide an overview together with the screenshots in the corresponding sections of the other trials.

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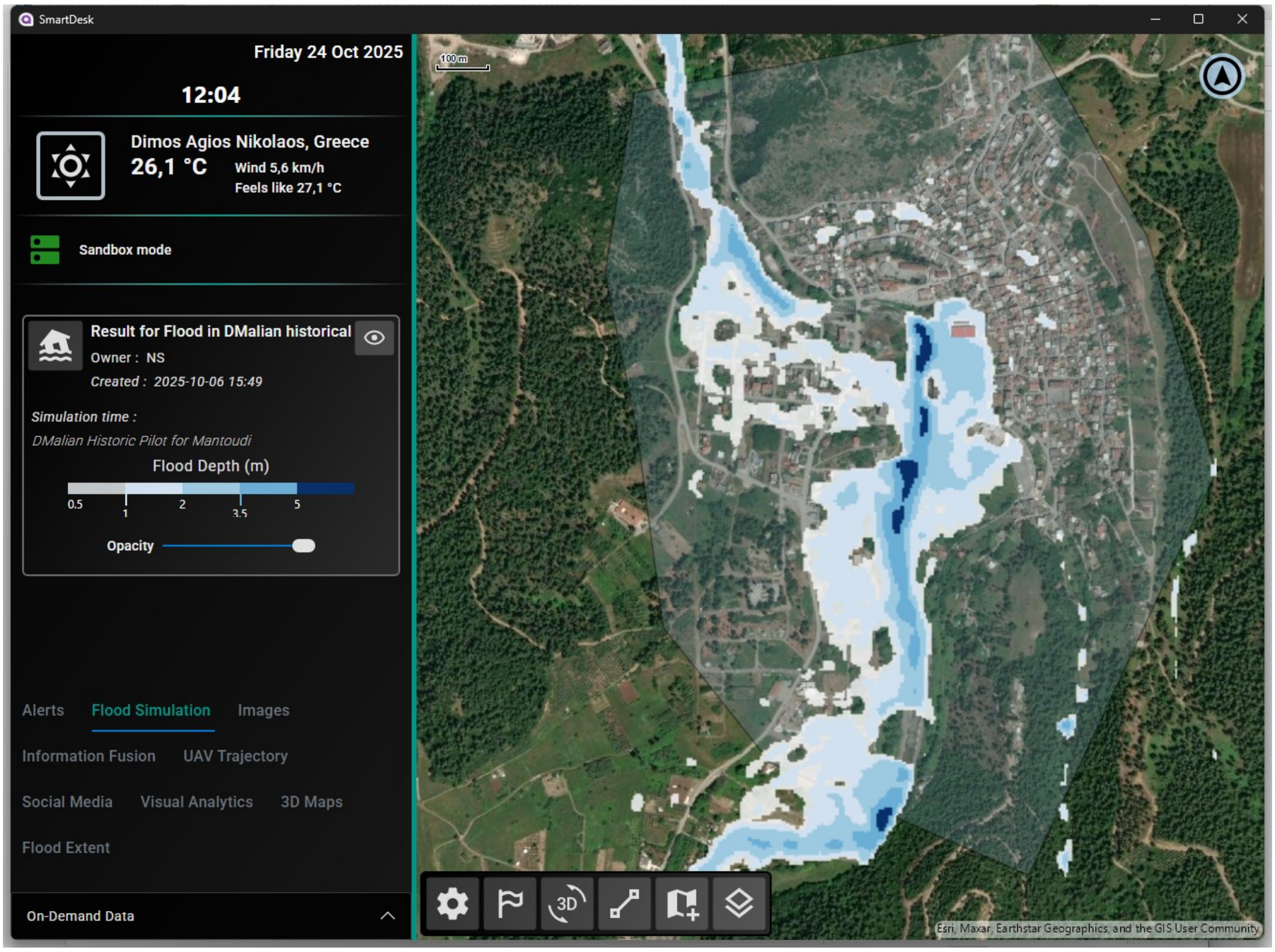

Figure 24: Flood simulation during D.MALIAN trial

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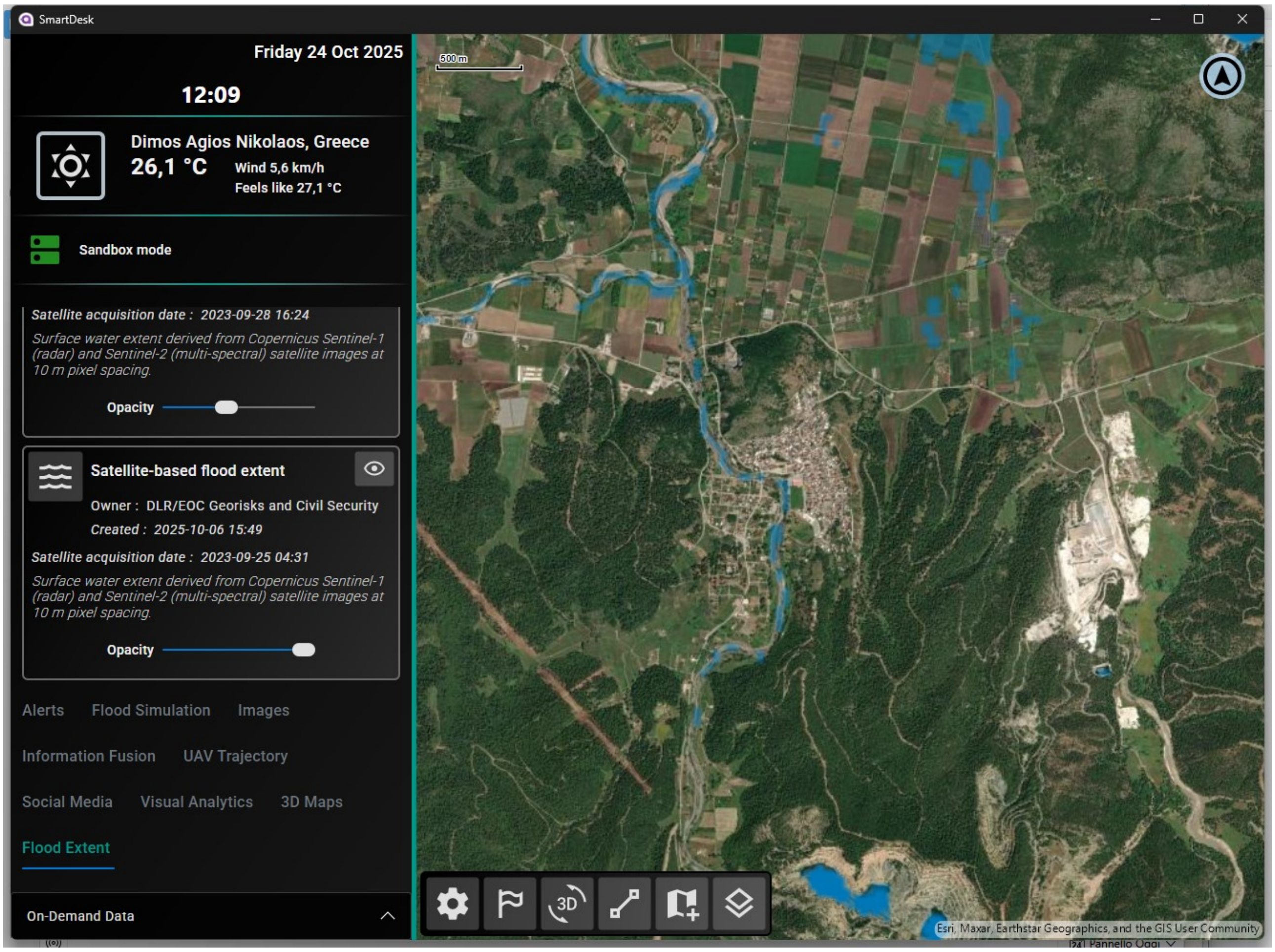

Figure 25: Satellite based flooded area analysis during the trial

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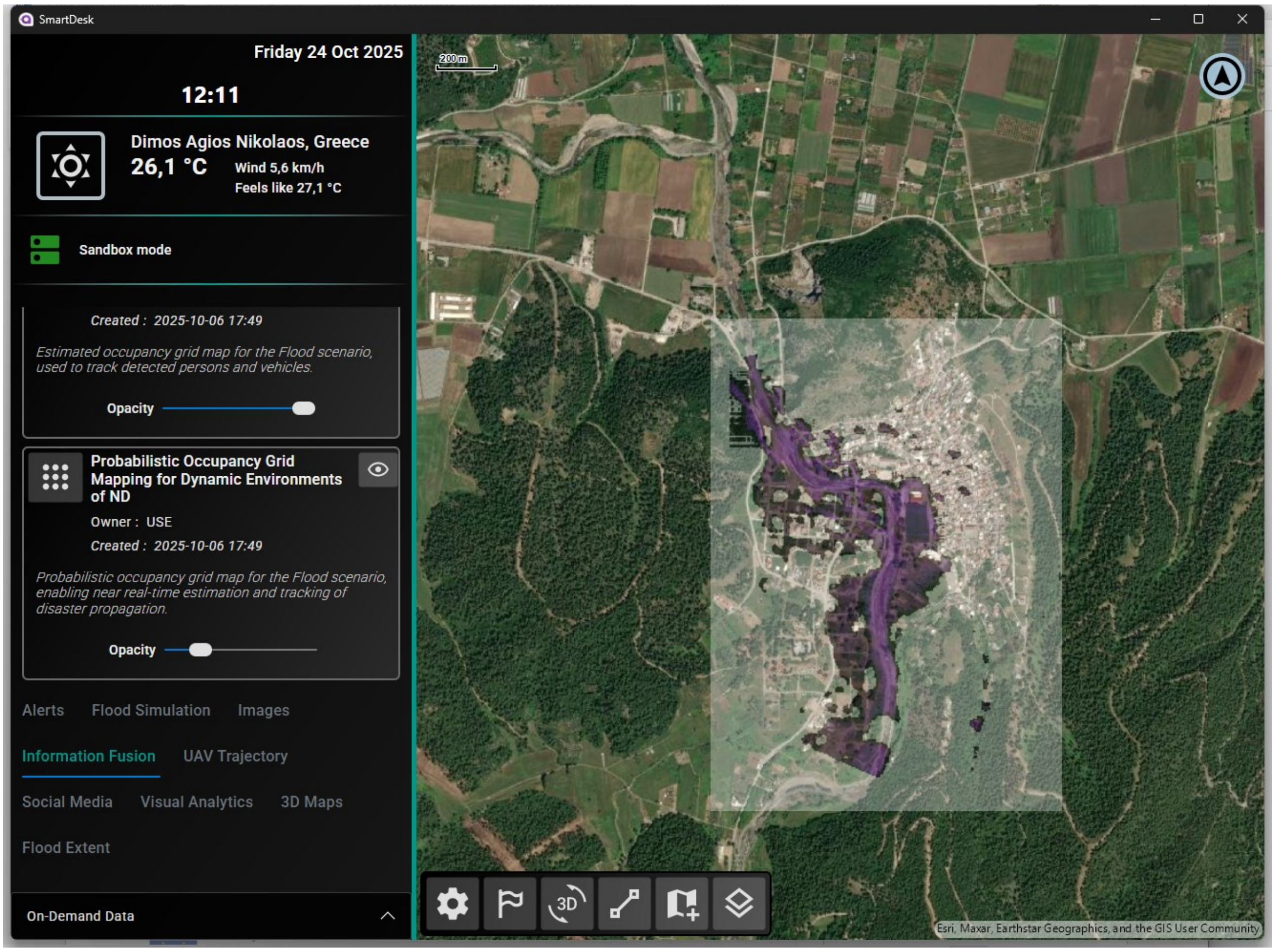

Figure 26: Probabilistic flood map generated from the information sources

6.4 Scenario 4: KAHY Forest Fires

In the next sub paragraphs the key information about the KAHY Forest Fires trial execution is summarized.

6.4.1 KAHY trial tested component

The following table shows which TEMA technologies were used to conduct the trial. Some of them are indicated as research only; in these cases, the technologies developed were not used in the trials.

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Table 6.4: report on tested components during KHAY trial

ID	Component	Owner	Used ?
TFA-tech-01	Concept discovery for latent space interpretability of deep neural networks	FHHI	only Research
TFA-tech-02	Human-comprehensible presentation of concept-based explanations	FHHI	no
TFA-tech-03	DNN robustness	AUTH	only Research
TFA-tech-04	Explainability for transformer base neural networks	ATOS	no
TFA-tech-05	Fire/smoke/person detection	AUTH	yes
TFA-tech-06	Fire/flood/background segmentation	AUTH	yes
TFA-tech-07	Person re-identification	ATOS	no
TFA-tech-08	Satellite-based flood detection and assessment	DLR-DFD	no
TFA-tech-09	Satellite-based Forest fire detection and assessment	DLR-DFD	yes
TFA-tech-10	Privacy preservation during visual analysis	AUTH	no
TFA-tech-11	Geo-social media analysis	PLUS	yes
TFA-tech-12	Sentiment analysis for short texts	AUTH	only Research
TFA-tech-13	Contrastive image-language models	ATOS	no
TFA-tech-14	Federated Learning	UNIME	only Research

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TFA-tech-15	Data scarcity, synthetic data generation pipeline	ATOS	no
PDM-tech-01	Forest Fire Simulation	TSYL	yes
PDM-tech-02	3Di Hydrodynamic simulation	NS	no
PDM-tech-03	Realistic 3D smoke modelling and fire detection	DLR-KN	no
PDM-tech-04	Drone planning	USE	yes
PDM-tech-05	Information fusion	USE	yes
PDM-tech-06	Data-fusion-based decision support and process triggering	DLR-DFD	
SV-tech-01	Drone-based image and data acquisition	USE	yes
SV-tech-02	Digital Enabler	ENG	yes
SV-tech-03	3D computer vision (SfM)/ Photogrammetry	Northdocks	yes
SV-tech-04	Geovisual Analytics	LAT40	yes
SV-tech-05	Geospatial information retrieval	AUTH	only Research
SV-tech-06	Extended Reality-based interactive visualisation system	Northdocks	no
SV-tech-07	Smartdesk Application	KAMK	yes

6.4.2 KAHY trial Business mission

Below we will show the diagram of the business mission that was tested during the trial.

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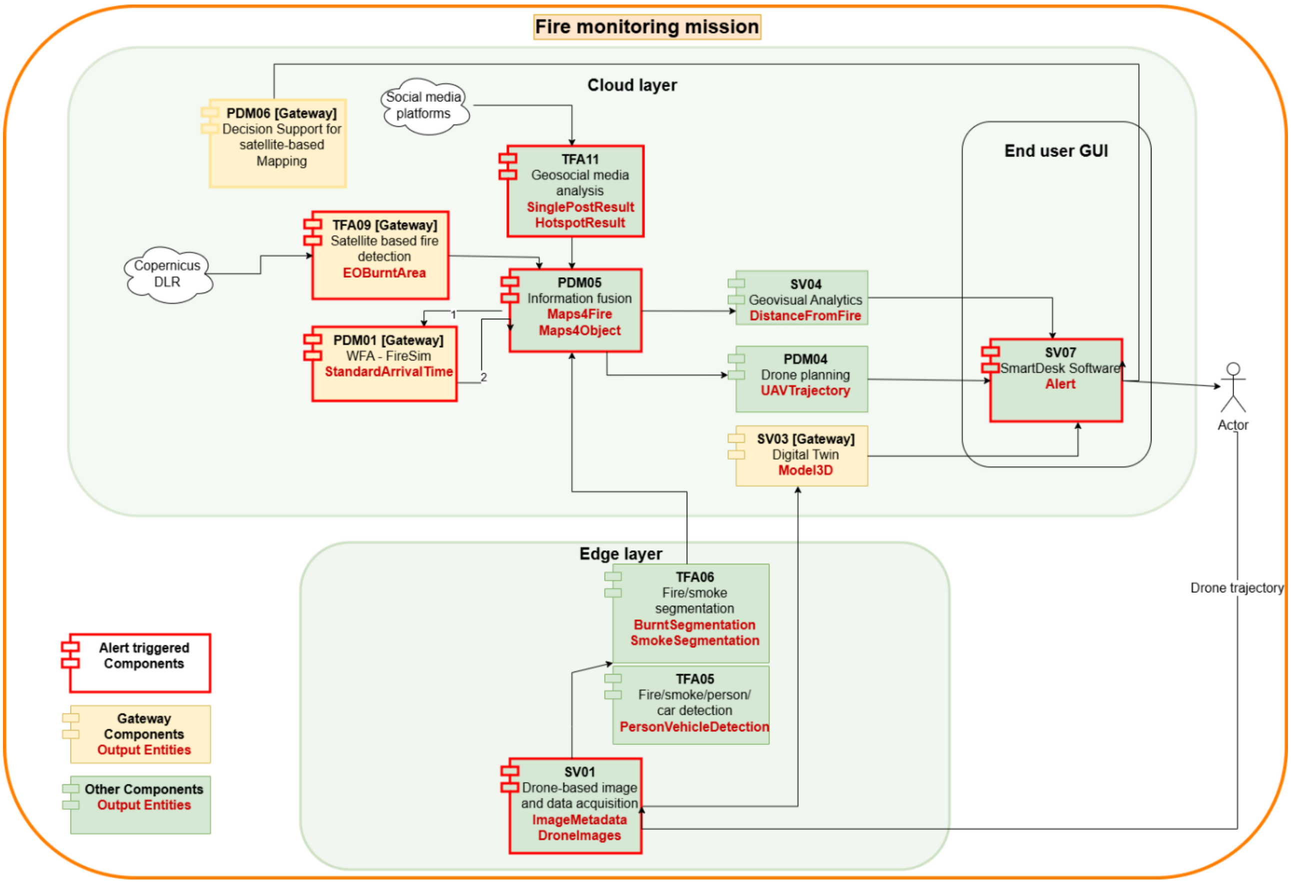

Figure 27: Business mission tested during the trial

6.4.3 Screenshots from the trial execution

In this section, we show some screenshots taken from SmartDesk during the trial run. Not all the features tested will be covered; the aim is simply to provide an overview together with the screenshots in the corresponding sections of the other trials.

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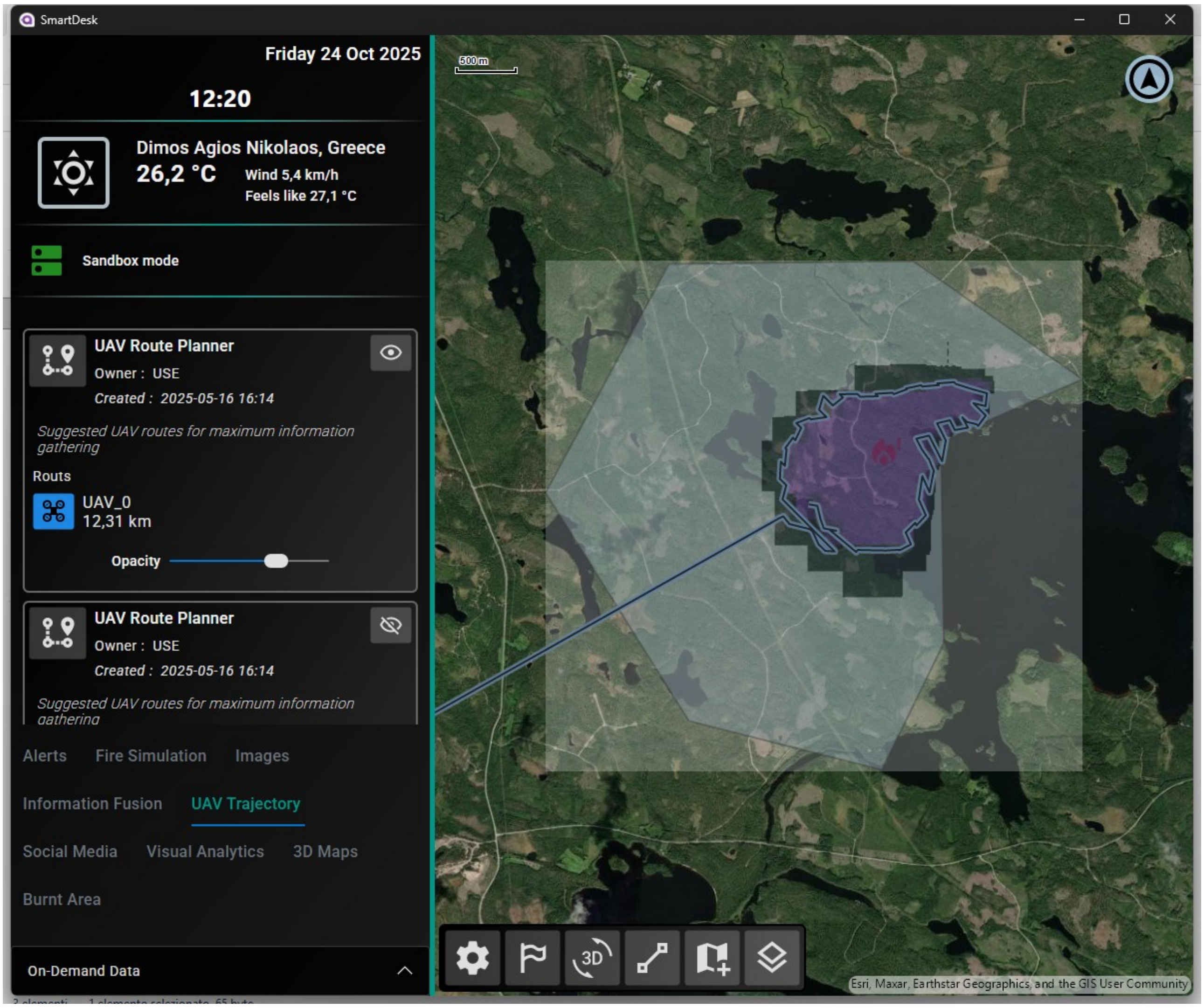

Figure 28: Drone trajectories calculated during the trial

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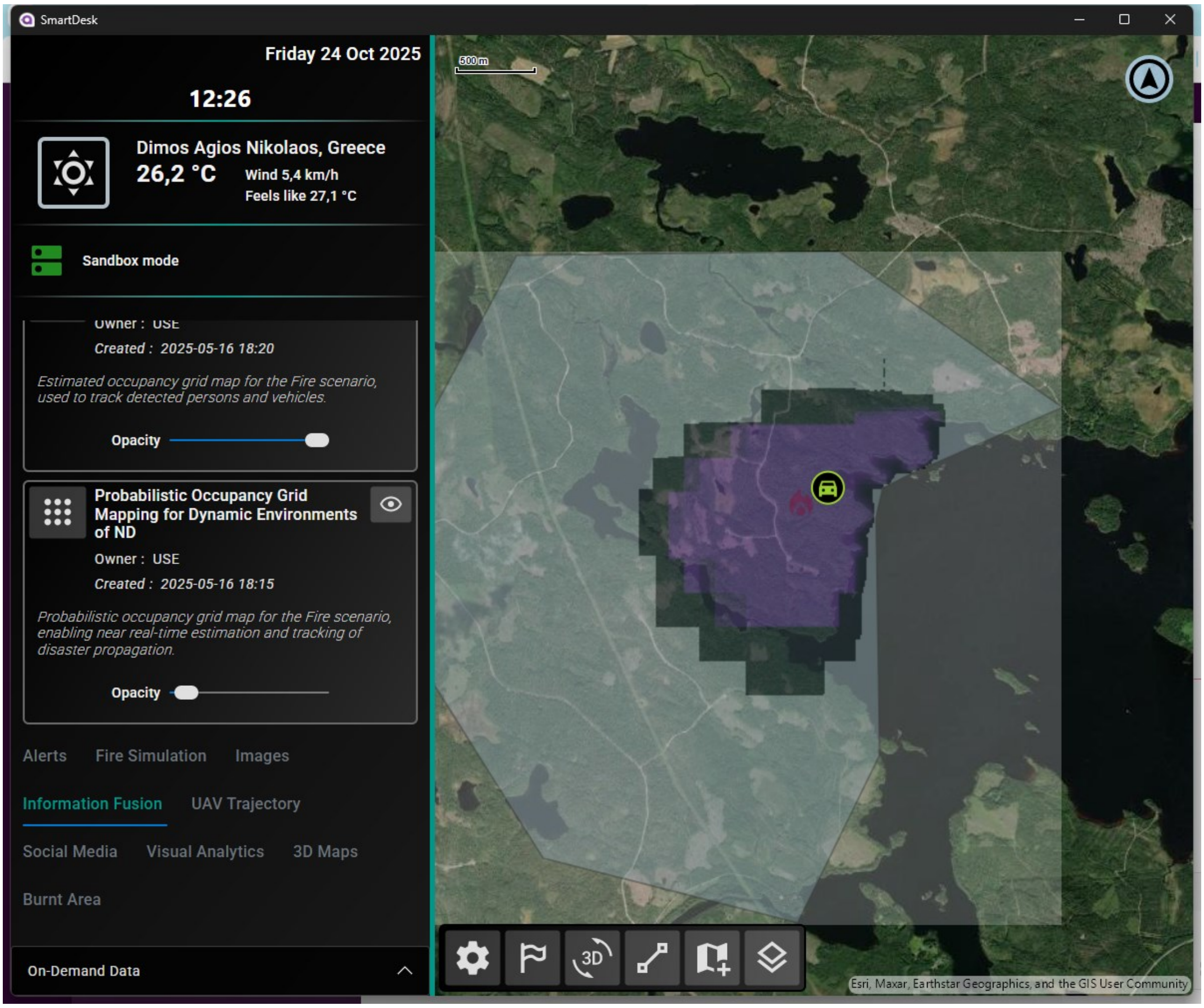

Figure 29: Probabilistic fire area with vehicles detection on map

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7 Conclusion

Up until now the TEMA solution has been thoroughly evaluated across four distinct Pilots/Trials, involving a wide range of end-users including first responders, civil protection authorities, and forest fire management teams. These real-world exercises provided invaluable insights into the operational needs and challenges faced during natural disaster scenarios.

Through the systematic collection and analysis of feedback from stakeholders, we were able to refine the architecture and technological components of the solution. This iterative process ensured that the platform evolved in alignment with actual field requirements, enhancing its relevance, usability, and effectiveness.

As we enter the final year of the project, our focus will be on consolidating the progress made thus far. We will continue to improve the TEMA Solution where feasible, prioritizing the seamless integration of all system components. This will be guided by the lessons learned during the Trials and the practical experience gained from direct engagement with operational teams.

Our goal is to deliver a robust, interoperable, and scalable platform that supports coordinated disaster response and strengthens situational awareness.

Key outcomes from this phase include:

- Successful deployment of TEMA containers and services in real pilot environments.
- Validation of key platform components such as AI processors, integration layers, and edge/cloud communication.
- Early user feedback and visual evidence from the trials, highlighting both the strengths and areas for further improvement.

Looking ahead, we will maintain an open dialogue with end-users to validate new functionalities and ensure that future developments remain grounded in real-world needs in the next four Trials planned for 2026.

In summary, D6.2 demonstrates that the TEMA platform is progressing as planned and is capable of delivering impactful tools for situational awareness, decision support, and operational coordination in the context of natural disaster management.

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