



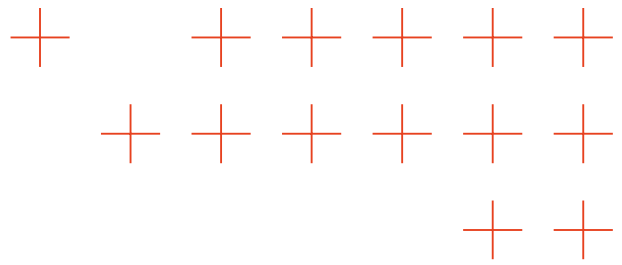
TEMA

TRUSTED
EXTREMELY PRECISE
MAPPING AND PREDICTION
FOR EMERGENCY
MANAGEMENT

D5.3

Interactive Digital Twin for critical emergencies

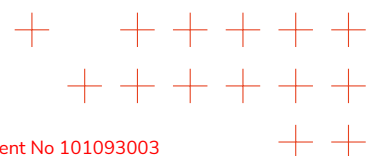


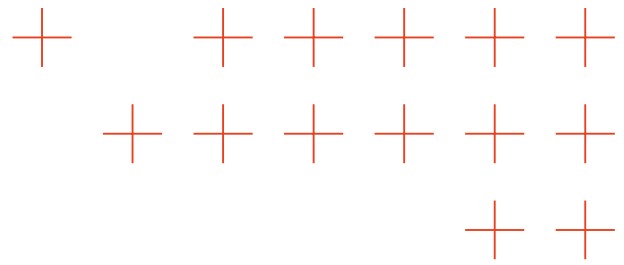


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D5.3- Interactive Digital Twin for critical emergencies			
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Author(s):	Silas Fuchs, Joachim Perschbacher, Filip Sever, Viktor Bezsmeranyi, Henri Partanen, Alisa Moilanen, Juha Moilanen		
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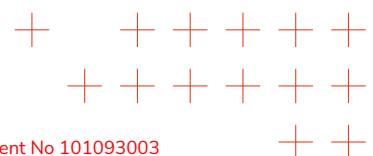


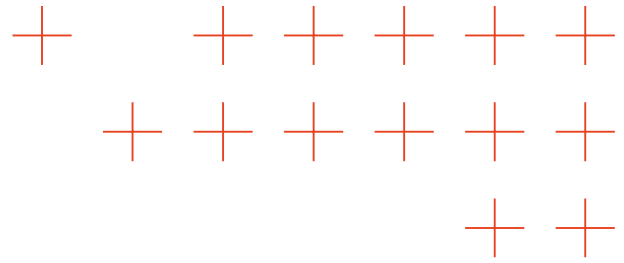
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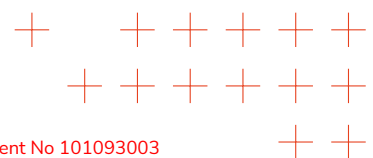
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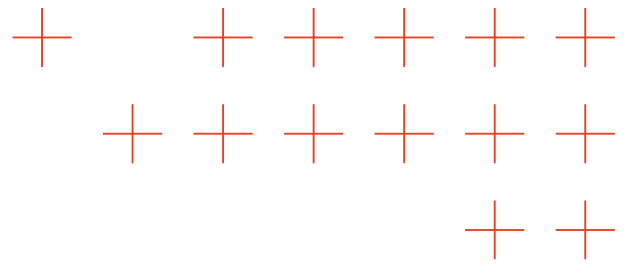
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1	ARISTOTELIO PANEPISTIMIO THES-SALONIKIS	AUTH	GR
2	DEUTSCHES ZENTRUM FUR LUFT UND RAUMFAHRT EV	DLR	DE
3	ENGINEERING - INGEGNERIA INFORMATICA SPA	ENG	IT
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4.1	ATOS SPAIN SA	ATOS SP	ES
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9	THE LISBON COUNCIL FOR ECONOMIC COMPETITIVENESS ASBL	LC	BE
10	LATITUDO 40 SRL	LAT40	IT
11	NELEN & SCHUURMANS TECHNOLOGY BV	NS	NL
11.1	NELEN & SCHUURMANS CONSULTANCY BV	NS C	NL
12	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	FHHI	DE
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17	DIMOS MANTOUDIYOU - LIMNIS - AGIAS ANNAS	D.MALIAN	GR
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19	BAYERISCHES ROTES KREUZ	BRK	DE
20	KAINUUN HYVINVOINTIALUE	KAHY	FI
21	INTERDISCIPLINARY TRANSFORMA- TION UNIVERSITY	IT:U	AT





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Authors

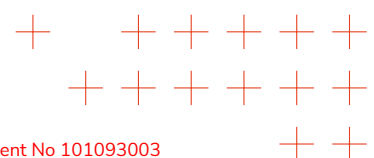
Name	Partner
Silas Fuchs	ND
Joachim Perschbacher	ND
Filip Sever	KAMK
Viktor Bezsmertnyi	KAMK
Henri Partanen	KAMK
Alisa Moilanen	KAMK
Juha Moilanen	KAMK

Editor

Name	Partner
Joachim Perschbacher	ND

Reviewers

Name	Partner
Antonio Salvatore Filograna	ENG



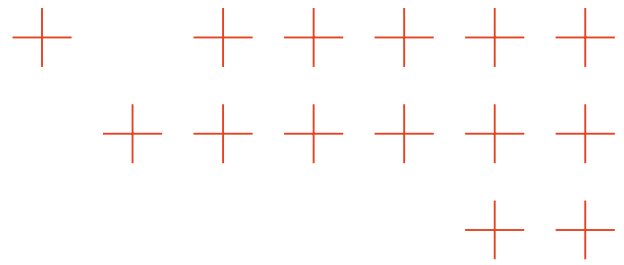
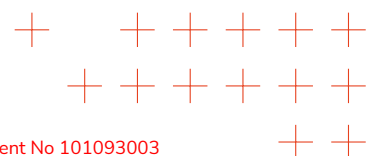
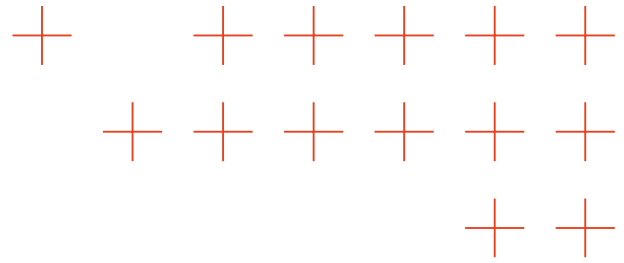


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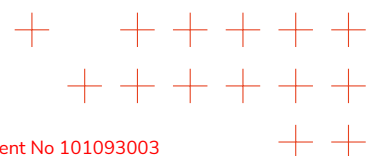
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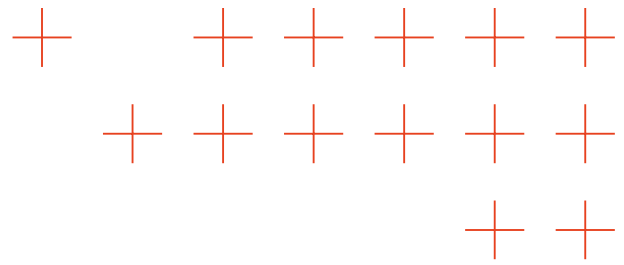




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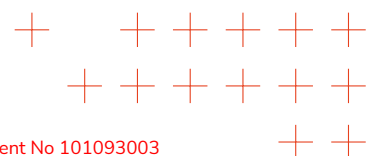
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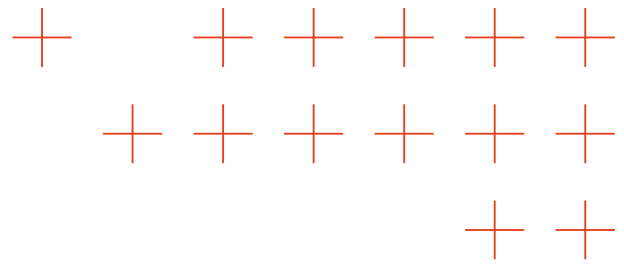




List of Terms and Abbreviations

Abbreviation	Meaning
AR	Augmented Reality
VR	Virtual Reality
MR	Mixed Reality
HMD	Head-Mounted Display
NDM	Natural Disaster Management
APK	Android Application Package
GDAL	Geospatial Data Abstraction Library
GeoTIFF	Geotagged Tag Image File Format
PBR	Physically Based Rendering
Unreal Engine	An open source real-time 3D creation tool for photorealistic visuals and immersive experiences.
WGS84	World Geodetic System 1984 (A global reference system for geospatial data)





Executive Summary

Deliverable D5.2 and D5.3, SmartDesk and XR Viewer: Geovisual Analytics and Immersive Visualization Tools, presents the combined outcomes of Work Packages 5.2 and 5.3 within the TEMA project. The work focuses on developing advanced visualization technologies that transform analytical and simulation results into intuitive, interactive, and operationally relevant visual experiences for decision makers and emergency responders.

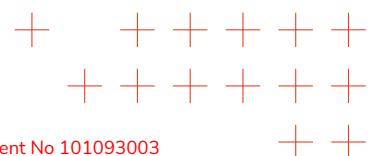
Two complementary systems have been developed: **SmartDesk**, led by **KAMK**, and the **XR Viewer**, led by **Northdocks**. Together, they form the dual visualization layer of the TEMA ecosystem.

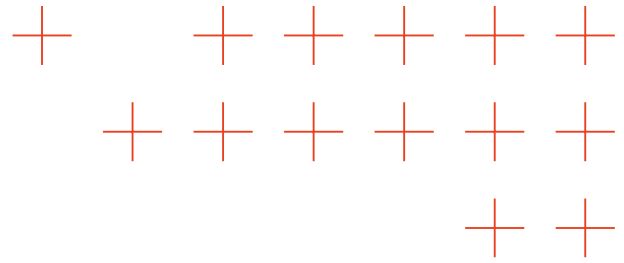
The **SmartDesk** is a cross-platform desktop application that functions as the central visualization and mission management interface of TEMA. It integrates data from a wide range of sources, including drone imagery, hydrological and fire simulations, social media analytics, and decision-support services. Built using .NET, Avalonia UI, and Mapsui, the SmartDesk provides efficient rendering, offline functionality, and responsive interaction across operating systems. Its modular design includes components for real-time communication, GDAL-based processing, and web service integration, ensuring interoperability with the FIWARE-based Digital Enabler and other TEMA subsystems.

The **XR Viewer** extends these visualization capabilities into the immersive domain. It enables users to explore and interact with 3D representations of simulation and analytical data using virtual and augmented reality devices. Developed in Unreal Engine 5 and integrated with Cesium for Unreal, it supports open geospatial formats such as 3D Tiles, GeoJSON, KML, and GeoTIFF. The system provides a fast, portable, and user-friendly visualization experience optimized for standalone VR headsets and tablets. Its ability to render realistic flood and hazard simulations in real time makes it ideal for both operational briefings and training purposes.

Together, these tools establish a **comprehensive visualization ecosystem** that combines analytical precision with immersive understanding. SmartDesk serves as the analytical and operational hub for monitoring and control, while the XR Viewer offers an experiential perspective that enhances comprehension, collaboration, and communication. Both systems are connected through the **Digital Enabler**, which guarantees interoperability and synchronized access to shared datasets.

The results achieved in WP5.3 confirm that combining desktop-based analytics with immersive XR technologies significantly improves situational awareness and decision support in emergency contexts. Future development will focus on enhanced integration between the two tools, user interface refinements, and validation during upcoming pilot trials such as the **BRK Flood Scenario in Ahrtal**.





1. Introduction

1.1. Purpose and Scope

Work Package 5.3 aims to deliver advanced visualization tools to enhance the interpretability of analytical and simulation data generated within TEMA. The objective is to provide decision makers and emergency management personnel with systems that present complex geospatial information in a clear and actionable form. This deliverable describes two complementary visualization technologies developed within WP5.3: **SmartDesk** (KAMK) and **XR Viewer** (Northdocks).

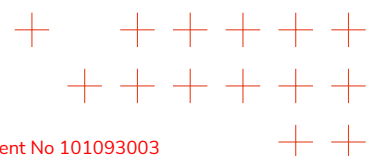
1.2. Relation to TEMA Objectives

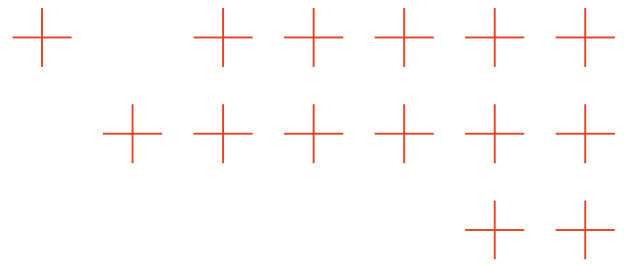
TEMA seeks to improve prediction, preparedness, and response for natural disasters by combining digital twins, simulation, and visualization. SmartDesk and XR Viewer serve as the primary user interfaces that connect end users to the projects analytical outputs. SmartDesk provides a comprehensive 2D and 3D mission management interface, while the XR Viewer delivers an immersive 3D experience for enhanced understanding and communication.

1.3. Structure of the Document

This document is structured as follows:

Chapter 2 summarizes the work carried out and contributions of partners. **Chapter 3** presents both visualization technologies in WP5.3: SmartDesk and XR Viewer. **Chapter 4** describes how both systems integrate into the wider TEMA architecture. **Chapter 5** concludes with key achievements and future developments.





2. Summary of Work Performed

2.1. Objectives of T5.2 and T5.3 Development of the TEMA Visualization Layer

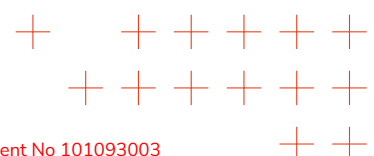
The primary objective of WP5.2 and WP5.3 is to develop visualization tools that allow users to access, interpret, and interact with simulation data from the TEMA platform. The work focuses on visual communication, geospatial rendering, and interactive interfaces for field and command-level operations.

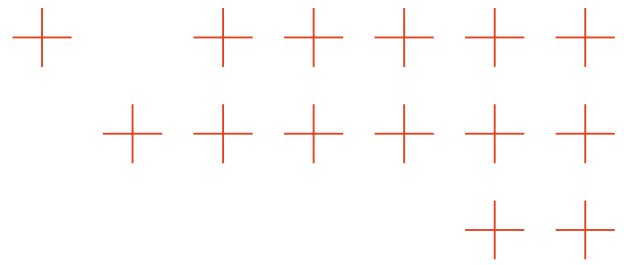
2.2. Partner Contributions

Two core development teams contributed to this work package: KAMK (SmartDesk): Development of a modular, cross-platform desktop application providing access to all TEMA data streams. Northdocks (XR Viewer): Implementation of an immersive visualization tool enabling 3D and XR-based exploration of simulation data.

2.3. Collaborative Efforts

Close collaboration between both teams ensured compatibility through the Digital Enabler. SmartDesk serves as the analytical visualization platform, while the XR Viewer extends the same data into immersive environments. Joint validation and demonstrations were conducted using flood datasets from Nelen and Schuurmans and use cases defined by BRK.





3. Visualization Technologies in WP5.2 and WP5.3

3.1. SmartDesk Technology (KAMK)

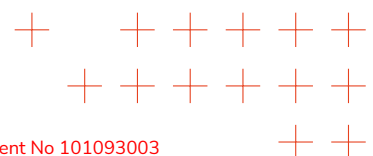
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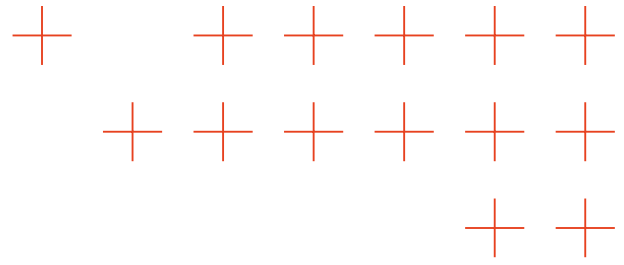
3.1.1. Concept Overview

SmartDesk is a desktop computer application for civil protection mission management. The application is a critical component of the TEMA platform, as it visualizes almost all the data and information that is collected, processed, and analyzed in the project. The SmartDesk combines and visualizes drone images, person and vehicle detection, flood simulation, fire simulation, social media analysis, map layers based on satellite imagery and decision support systems with severe weather alerts and recommendations, and more. To ensure hardware compatibil-



Figure 1. The SmartDesk application is running on a laptop.





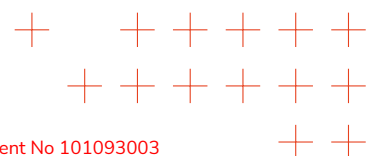
ity and access for both technical partner and end users in the project, the application updates and builds for both Windows and Linux operating systems. In addition, a wide variety of hardware configurations are used to test the application performance on, including Raspberry Pi single board computers, high-performance desktops and laptops, to touchscreen-centric table-computers.

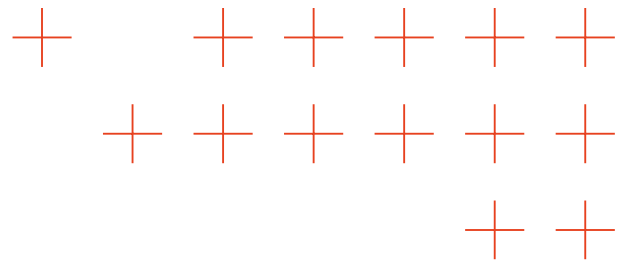
Although SmartDesk is a desktop application, its design philosophy emphasizes a mobile-like user experience. The interface is intended to be simple, intuitive, and easy to navigate, minimizing complexity for first responders and other end users.

This design approach is also critical for supporting touch input, ensuring that all controls and interactions remain accessible and efficient on touch-enabled displays. Following end user feedback, both touch controls and keyboard and mouse input have been implemented.



Figure 2. The SmartDesk application running on the touchscreen table at KAMK.





3.1.2. Business Mission

To organize different kinds of data and describe the relationships between system elements, the platform uses a structured, mission-based approach. This approach ensures that all information from raw sensor input to predictive modeling and visualization follows a well-defined, traceable flow within the system.

This life cycle structure enables the TEMA platform to maintain consistency between analytical modules, data storage, and visualization components. It also ensures that decision-makers always have access to relevant, contextualized information, reflecting the status of operations.

In the SmartDesk, a business mission acts as the central organizing entity through which users can monitor real-time updates, adjust operational parameters, and initiate new analytical computations when needed. Therefore, SmartDesk serves as the primary user tool within the TEMA platform, providing a unified environment for visualization, interaction, and control of mission-related data and processes.

The following sections of this chapter outline the technical specifications of the SmartDesk and its overall connection into the TEMA system.

3.1.3. Technical Description and Platform Choice

The SmartDesk application is developed on the .NET desktop platform, enabling it to function as a native-class desktop application with enhanced safety compared to traditional native development. It offers efficient use of system resources, advanced memory management, and the ability to locally store and process files. This enables SmartDesk to perform a wide range of operations offline, which is essential for emergency services such as fire departments, the Red Cross, and other civil protection organizations. Compared to web applications, SmartDesk delivers higher performance and reliability.

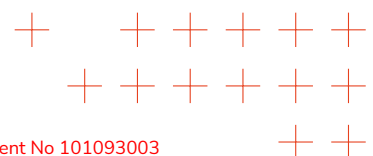
3.1.4. Challenges

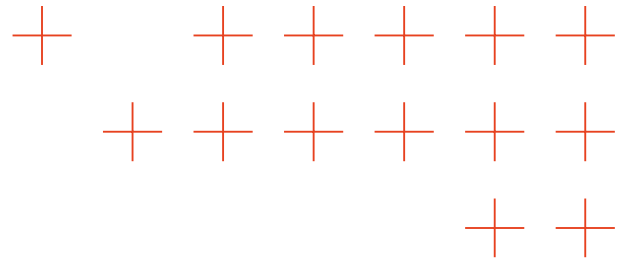
As with any platform, there are some limitations.

Heterogeneous data handling: The application must process a wide variety of data types including photos, videos, and geospatial datasets. This requires integrating multiple software components, libraries, and frameworks into a single coherent system, while avoiding dependency conflicts and ensuring overall stability and performance.

Cross-platform integration: Some of the technologies used in SmartDesk were originally developed for web-based applications. Integrating these technologies into a desktop environment presents additional challenges, requiring adaptation or bridging layers to ensure compatibility and maintain responsiveness.

Performance and scalability: Processing large datasets, especially geospatial and multimedia content, demands efficient memory management, asynchronous operations, and optimized rendering pipelines to maintain smooth user interaction.





3.1.5. Implementation Stack

To ensure reliability, performance, and maintainability, SmartDesk leverages a selection of well-established, open-source components with proven track records, extensive user bases, and active community support:

.NET Platform (Microsoft). The core framework for developing native-class, cross-platform applications. .NET provides robust performance, strong security, and long-term support.

Avalonia UI. An open-source, cross-platform UI framework for .NET, supporting Windows, macOS, Linux, iOS and Android. Avalonia provides a modern UI toolkit with a custom rendering engine for complex, high-performance applications from a single codebase. A dedicated desktop application allows for a high degree of customizability to accommodate various user interface elements, interaction mechanisms, offline functionality, and overall performance of the technology.

Mapsui. A .NET mapping component supporting points, lines, polygons, OpenStreetMap tiles, OGC standards, offline maps, and static map image generation. Mapsui integrates with UI frameworks like Avalonia and offers touch and mouse event handling, suitable for both desktop and mobile applications.

NetTopologySuite (NTS). A .NET GIS library for modeling and manipulating 2D geometric objects. Provides numerous geometric functions and predicates, compliant with the Simple Features Specification for SQL (Open GIS Consortium), widely used for spatial data processing.

LibVLCSharp. A cross-platform audio and video API for .NET based on VideoLAN's LibVLC library. Enables robust multimedia playback on desktop, mobile, and server platforms.

MetadataExtractor. A .NET library for reading metadata from images, movies, and audio files.

SQLite. A lightweight, serverless, self-contained SQL database engine ideal for local storage, offering reliability, simplicity, and minimal setup.

Additional GIS libraries. Libraries such as LibTiff.NET and SharpKml support various geospatial data formats and specialized processing.

Both Avalonia and Mapsui use Skia under the hood for 2D graphics rendering. Skia is a highly performant, widely used graphics library powering web browsers like Chrome and Firefox, mobile platforms like Android, and numerous desktop and embedded applications. Its reliability and efficiency make it ideal for rendering complex 2D graphics across multiple platforms.

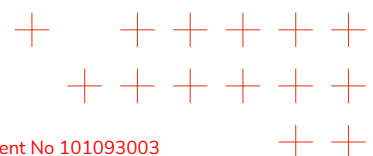
All the components listed above are open source, allowing the code to be adapted or extended as needed to meet specific requirements and tasks.

3.1.6. Modular Architecture

Core Module

The Core Module is responsible for the primary processing of geospatial data within SmartDesk. It is UI-agnostic and is built on Mapsui. Mapsui uses a feature-based data model, where each feature consists of geometry (Point, LineString, or Polygon) and associated attributes, organized into layers for rendering and management.

The main task of the Core Module is to prepare and pre-process data for visualization. SmartDesk is not intended to support every possible data format or act as a universal geospatial tool; instead, the module implements a specific set of data handling methods required to work with data provided by TEMA platform partners. For example:



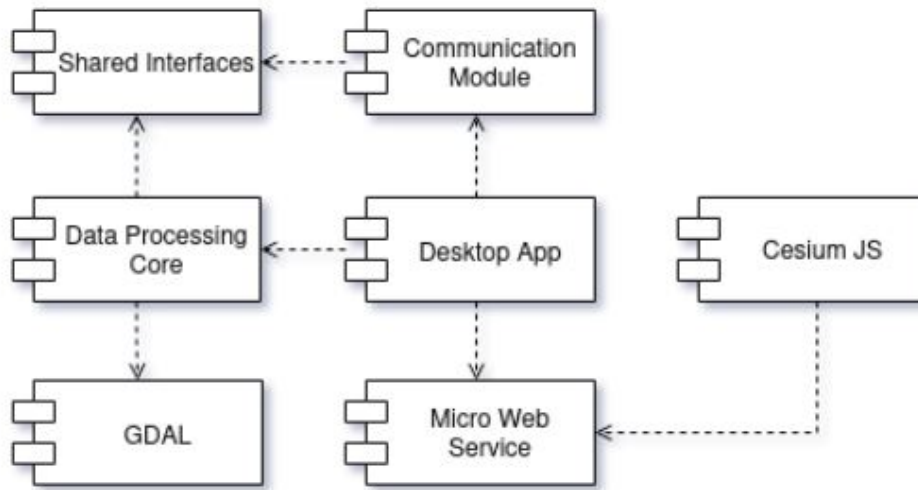
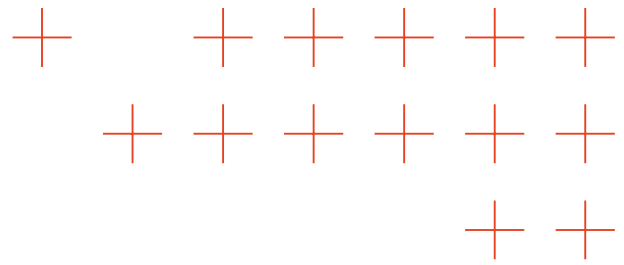


Figure 3. Module dependency diagram of SmartDesk

PDM-tech-02: 3Di Hydrodynamic Simulations and TFA-tech-08: Satellite-based flood detection and assessment. To display GeoTIFF datasets, the module extracts raster images for Mapsui layers, leveraging the Skia graphics engine for efficient rendering.

PDM-tech-01: Fire Simulation and SV-tech-03: 3D computer vision and Photogrammetry. It supports a subset of KML files to visualize vector outputs and Orthomosaic maps.

TFA-tech-06: Fire, smoke, flood background segmentation. The module provides methods for processing images and masks for photos, enabling proper integration of multimedia data into geospatial layers.

Desktop Module

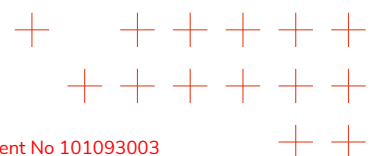
The desktop module of SmartDesk is built using the MVVM (Model-View-ViewModel) architecture, a well-established pattern widely used for both desktop and mobile applications. MVVM helps separate the UI logic from the business and data logic, making the application easier to maintain, test, and extend.

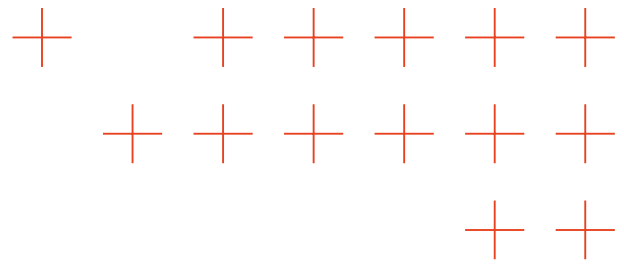
In addition to the view models, there is a layer of local services that connect to data sources that are not directly related to the TEMA platform. Examples include:

Weather services
 Geocoding services to obtain addresses from coordinates and vice versa
 Altitude services to determine elevation at a specific location
 Other data providers, which can be specific to a country, region, or a particular type of first responder
 These local services are important for first responders, as some provide information critical to firefighters, while others may support other emergency services.

The module also leverages .NET Reactive UI, which implements the reactive programming model. This enables the UI to automatically respond to changes in the underlying data, supporting a responsive and event-driven application where updates propagate seamlessly from the data layer to the interface.

All application data is stored in a local database, which serves as the single source of truth. Data flows from the database and internal services to the UI, and all operations are performed asyn-





chronously, ensuring smooth performance and responsiveness even during intensive data processing. By default, the app uses SQLite, but it can be replaced with other well-known databases depending on the hosting model, for example Postgres, MS SQL Server, or MySQL. The module is implemented using Avalonia, but the architecture allows the integration of new UI technologies, such as .NET MAUI from Microsoft or the Uno Platform, without affecting the functionality of the core application.

Communication Module

The next module is a Web API with SignalR (WebSockets) support, which provides a real-time connection between the desktop application and the TEMA platform hosted in the cloud. Its primary functions are to:

Subscribe to events from the platform and notify one or multiple client applications. Validate incoming data from various components and convert it into the internal format. Provide access to S3-compatible cloud storage, allowing the desktop application to retrieve data through secure signed URLs. Enable the user to launch a business mission directly from SmartDesk.

Micro Web Service Module

The Micro Web Service Module bridges the gap between data visualizations primarily designed for the web, such as 3D tiles, and the SmartDesk desktop application. It provides a local web service that enables communication between the SmartDesk and web-based viewer built on Cesium.

The service runs locally, receiving commands from SmartDesk, transmitting them to the web interface, and providing pre-processed data prepared by the core application. For efficient inter-process communication, it can use Unix sockets or Windows named pipes, minimizing overhead and ensuring high performance.

For rendering web content, the service can use either an embedded Chromium-based view (e.g., CEF or WebView2) or a standard web browser (recommended). This architecture also allows the web interface to be displayed on a separate device within the local network, such as a projector or a second workstation, providing flexibility in deployment and visualization setups. By using a local micro web service, SmartDesk can integrate the web into the desktop environment.

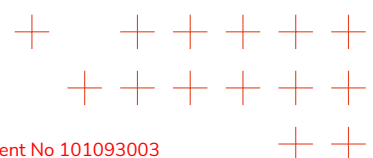
GDAL Processing Module

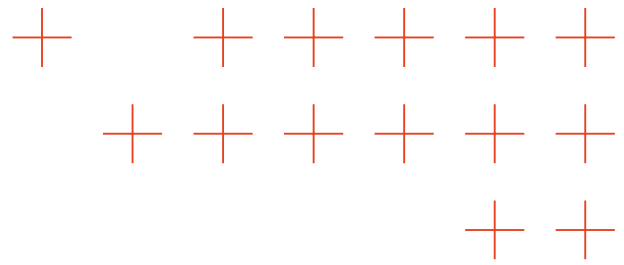
In certain cases, the application requires more advanced tools for example, to reproject GeoTIFF images on the fly. For this purpose, SmartDesk includes a module that enables the use of GDAL (Geospatial Data Abstraction Library), a powerful open-source library for raster and vector geospatial data processing. The module operates as a console-based external process, which is invoked by the main application to perform specific tasks. This approach allows SmartDesk to execute required geospatial operations in an isolated environment, ensuring stability and preventing heavy computations from affecting the user interface. Once the processing is completed, the main application visualizes the results directly in the interface.

Additional Modules

Several additional modules are included to manage data interfaces and integration between the main modules. Their primary role is to connect core, desktop, web API, and micro web service modules, handling data exchange, formatting, and synchronization.

This modular design provides flexibility, simplifies testing, and enables SmartDesk to adapt to emerging UI frameworks while maintaining its core capabilities.





3.1.7. Deployment and Hosting

SmartDesk is distributed as a self-contained .NET build, meaning all necessary dependencies are included in the package. On Windows, the application can run directly without installing additional components. On Linux, a few system libraries may be required, depending on the specific configuration and functionality used.

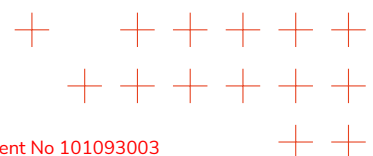
The modular architecture of SmartDesk enables flexible deployment options. The module responsible for communication with the TEMA cloud platform can be hosted in the cloud itself, distributed as a Docker image, or deployed locally within a secure environment. In the latter case, the system can operate in an edge configuration, where all processing and visualization are performed locally while a secure VPN connection links the local network to the cloud platform.

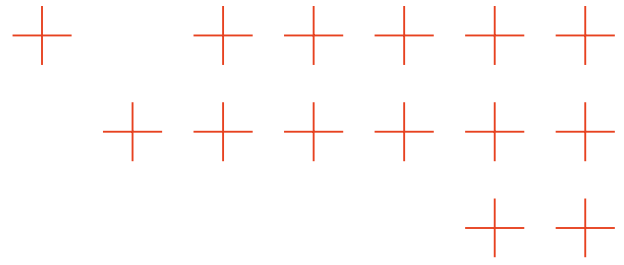
The SmartDesk desktop application can run on any modern personal computer with at least 8 GB of RAM and a graphics processor supporting OpenGL 3.0 or newer. In some environments, the underlying Skia graphics engine can also make use of Vulkan for improved rendering performance. For 3D map visualization based on Cesium, support for WebGL is required.

Since both Avalonia and Mapsui rely on the Skia engine, SmartDesk benefits hardware acceleration and cross-platform consistency across Windows and Linux. In addition, SmartDesk supports touch-screen interaction, making it suitable for use on large touch-enabled displays or table-sized screens in command centers, as well as on mobile laptops in the field. This feature is particularly valuable for first responders, who require interactive visualization and control in dynamic or team-based environments.

3.1.8. Integration

Following the business mission model, SmartDesk visualizes nearly all types of data collected or generated by the TEMA platform. Some components serve as intermediate data for other system elements and may be hidden from standard users during normal operation. However, during development or in subsequent iterations aimed at improving the platform, SmartDesk can be used as a tool to visually inspect these intermediate data flows. This capability not only provides clear insights into the systems internal processes, but also simplifies testing, debugging, and validation of new features and updates.





Alert

To initiate a business mission, SmartDesk uses an alert mechanism based on the Common Alerting Protocol (CAP) Version 1.2. The primary purpose of this component is to define the parameters required to launch a new business mission. The application supports both visualization and creation of alerts, enabling users to configure key mission parameters directly within the interface. Users can specify an Area of Interest (AOI), define critical points such as ignition points in the case of a wildfire scenario, and set other mission-specific parameters.

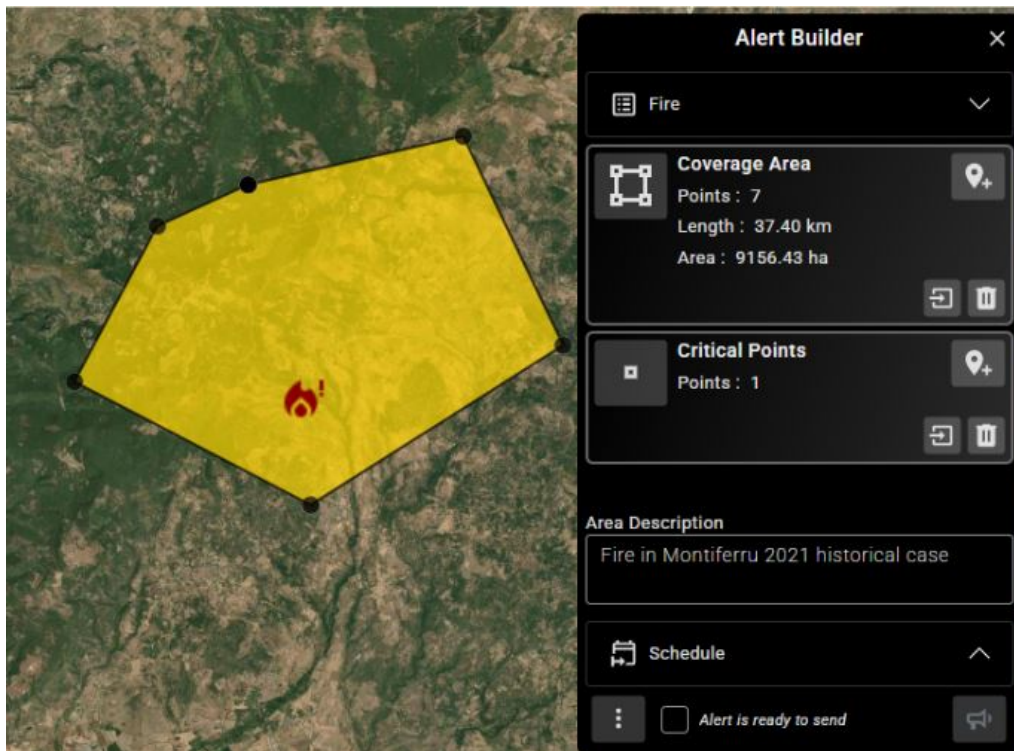
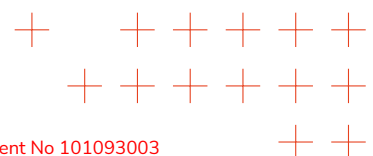
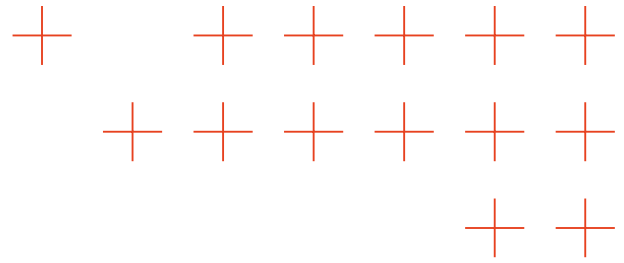


Figure 4. Interface for defining an Area of Interest and creating a new alert





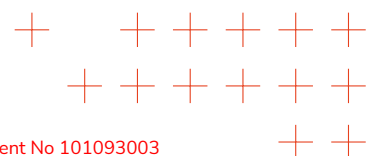
Drone images and data acquisition (SV-tech-01)

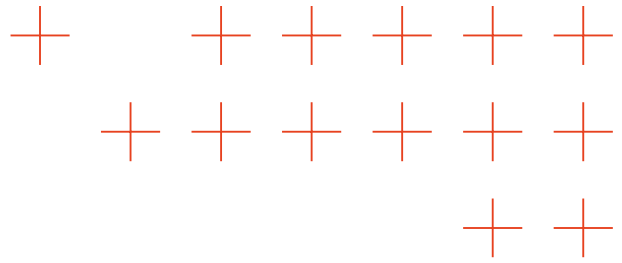
This component is responsible for acquiring aerial photographs and related sensor data from unmanned aerial vehicles (UAVs). It operates at the Edge Layer, which consists of the drones themselves and a local base station serving as a communication bridge to the TEMA platform. Captured images are processed and uploaded to the system for further analysis and visualization within SmartDesk. This enables near real-time integration of field data into the operational workflow.

On the SmartDesk users can browse captured photographs grouped by device and flight session. Each image can be viewed either in a full-size viewer or directly on the map interface, providing spatial context and ease of navigation. Along with the image itself, SmartDesk also displays all related analytical data such as masks and detections allowing users to inspect both the raw and processed results for each photo in a unified interface.



Figure 5. Drone images layer (SV-tech-01).



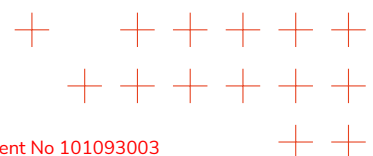


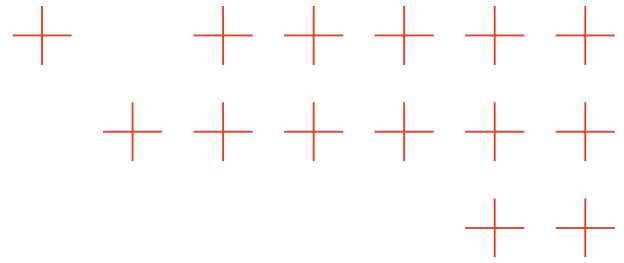
Person and Vehicle detection (TFA-tech-05)

This component analyzes drone imagery to automatically identify and highlight people and vehicles, enabling rapid localization of those in need and supporting more efficient rescue operations. SmartDesk receives the detected objects as bounding boxes in JSON format and overlays them on the corresponding images for visualization.



Figure 6. Person and Vehicle detection (TFA-tech-05).



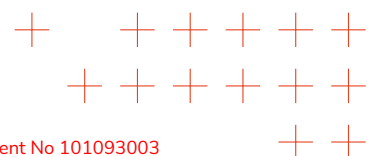


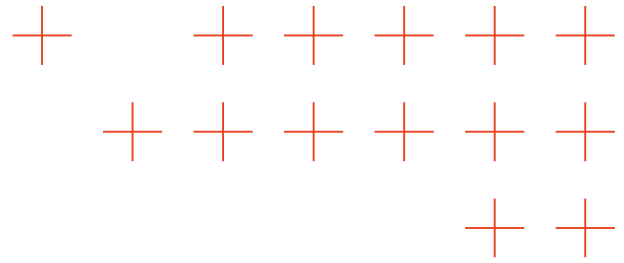
Fire, smoke and flood background segmentation (TFA-tech-06)

This component processes images captured by drones to automatically detect and highlight critical areas during emergency situations such as fire boundaries and affected zones. The generated segmentation masks are overlaid on the images by SmartDesk.



Figure 7. Smoke and Fire segmentation (TFA-tech-06).





Wildfire Analyst Fire Simulation (PDM-tech-01)

This component provides wildfire behavior simulations, including Arrival Time, Rate of Spread, Fireline Intensity, Flame Length, and Fire Paths. SmartDesk receives simulation outputs in KML and GeoTIFF formats, processes the data for rendering in Mapsui, and visualizes it using corresponding legend files to ensure consistent color mapping and interpretation.

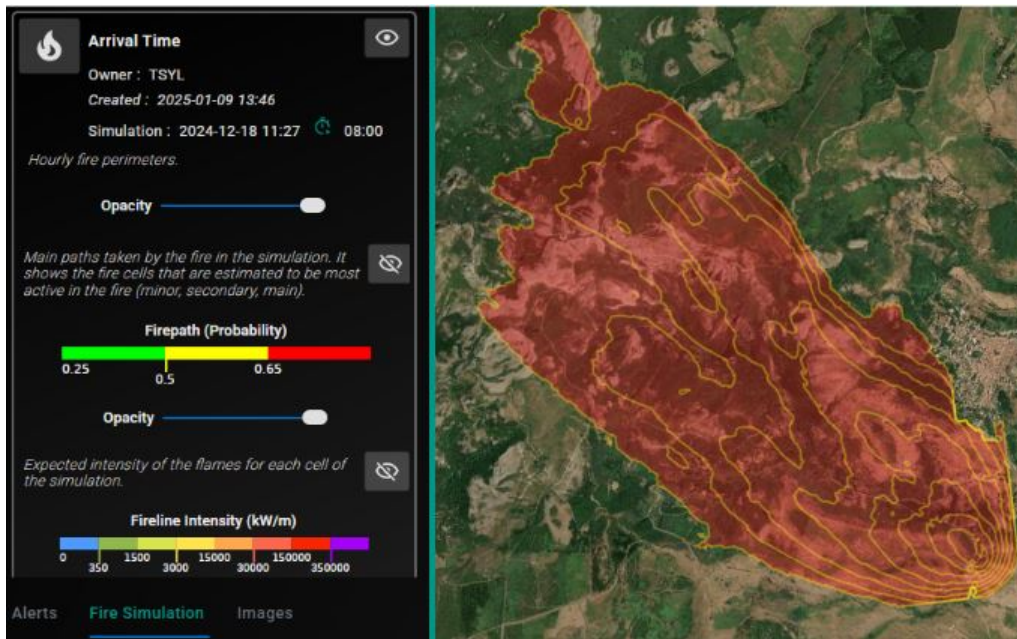
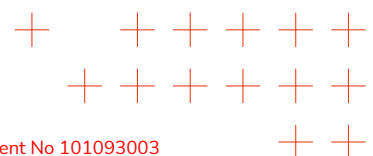
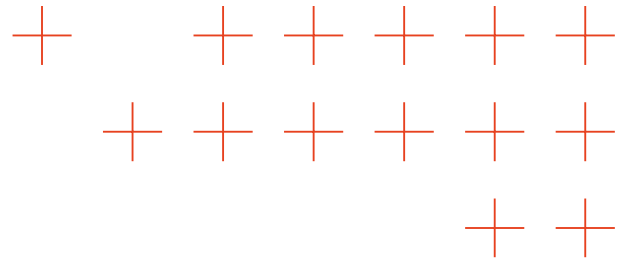


Figure 8. Fire Arrival Time, 8 hours simulation (PDM-tech-01).





3Di Hydrodynamic Simulations (PDM-tech-02)

This component provides forecasted simulations of flood propagation based on meteorological data and hydrological models. SmartDesk receives results in GeoTIFF and 3D Tiles formats. The GeoTIFF data is visualized on the 2D situational map as a color-coded depth mask, representing water levels across the affected area.

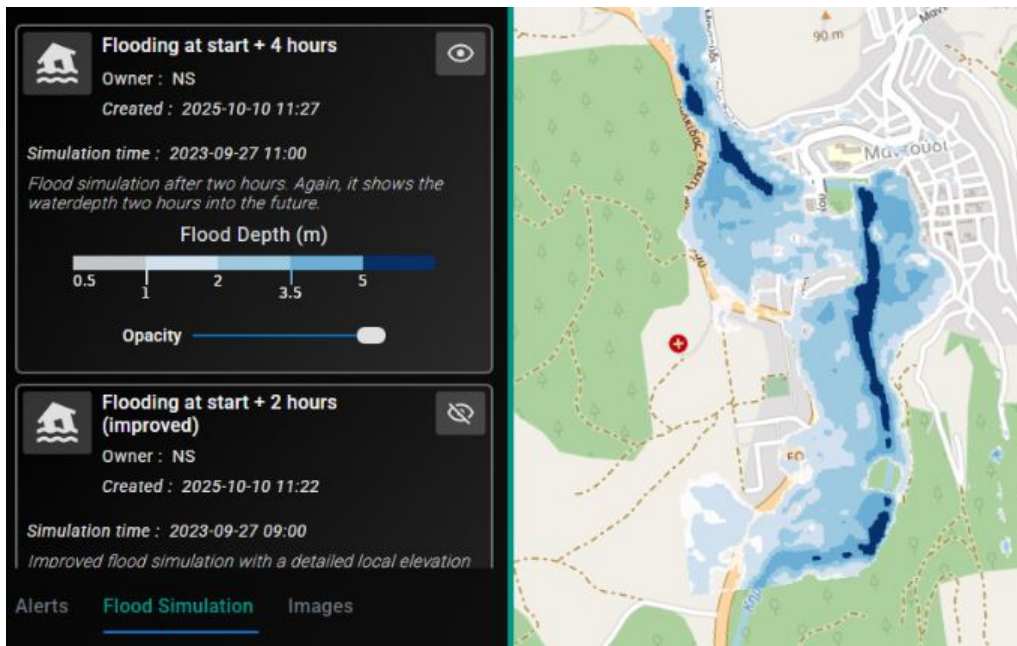
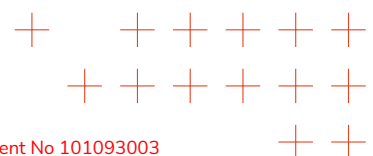
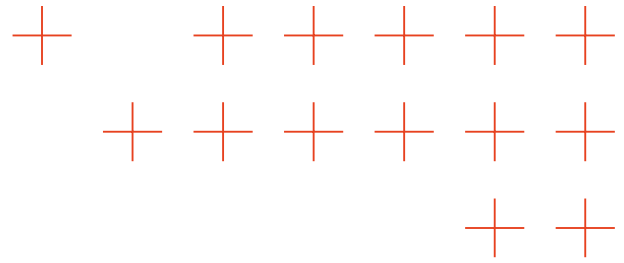


Figure 9. Flood Arrival Time, 8 hours simulation (PDM-tech-02).





Geo-social media analysis (TFA-tech-11)

The component analyses social media content to highlight affected areas and provide crowd-sourced information in real time. Processes posts from multiple social media platforms, extracts location and identifies thematic clusters, emotions and activity hot spots.

Within SmartDesk, users can visualize the distribution of emotions and sentiment from social media posts. Users can also filter and explore posts either on the map according to their geolocation or in a structured list view. Individual social media posts on the map are colored by their sentiment. The interface also includes an image viewer for examining media attached to posts. Additionally, SmartDesk displays the output of the TFA-tech-12: Sentiment analysis for short texts, which automatically generates textual descriptions of images, helping users better understand visual content shared during emergency events.

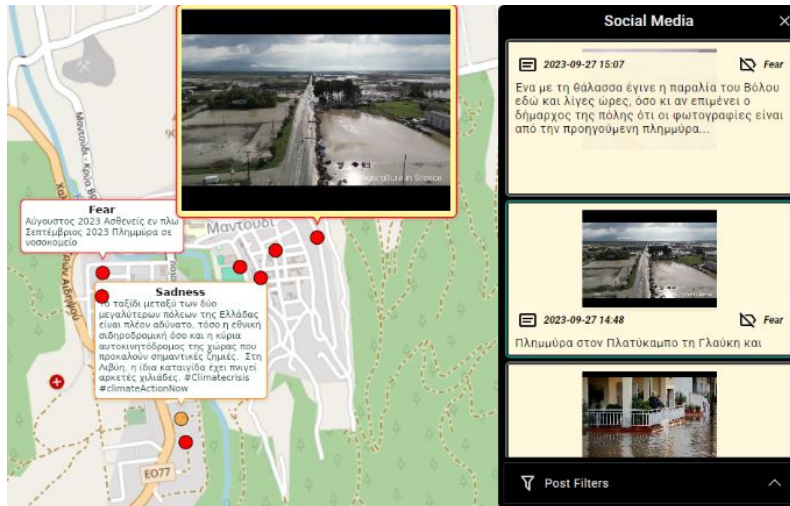


Figure 10. Social Media single post layer (TFA-tech-11).

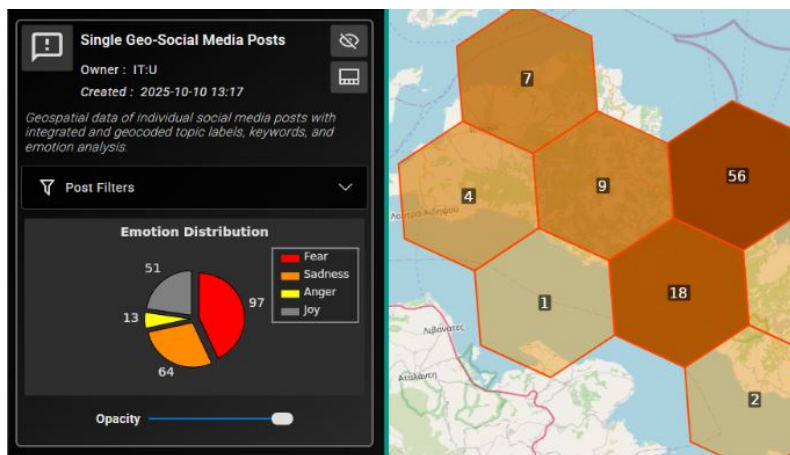
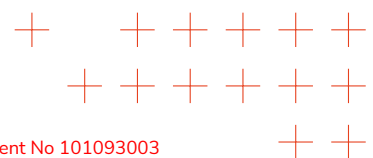
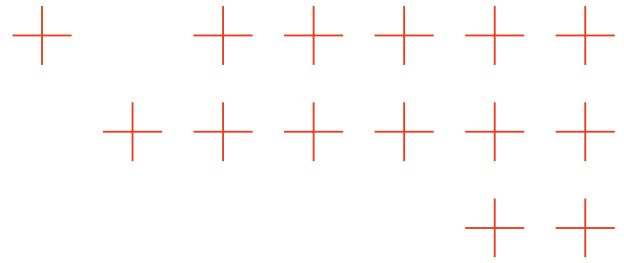


Figure 11. Emotion distribution chart and hexagonal binning hot spot analysis of social media activity clusters related to specific keywords (TFA-tech-11).





Visual analytics (SV-tech-04)

SmartDesk receives geospatial analytics data that enables the visualization of buildings and infrastructure located within potential risk zones. Each feature in the dataset includes a calculated distance from an emergency event such as wildfire or flood. On the map, objects are color-coded according to their risk level, providing an immediate visual understanding of exposure.

Users can apply distance-based filters to focus on specific affected areas. The dataset also includes a list of critical infrastructure elements, such as schools, hospitals, fire stations, and police departments, which are highlighted for rapid situational assessment and prioritization of response actions.

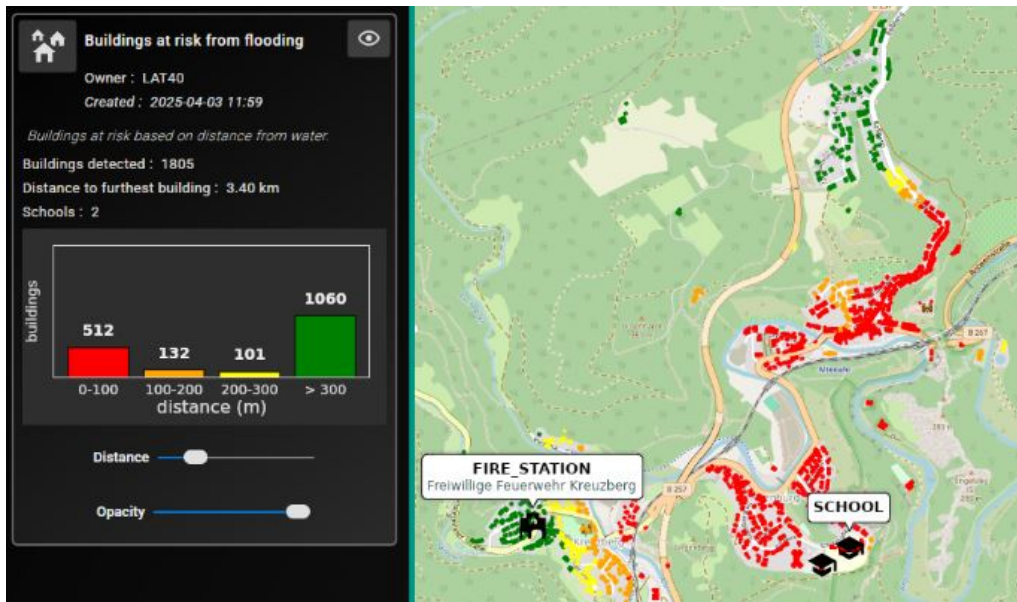
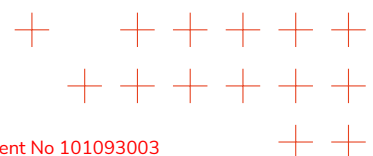
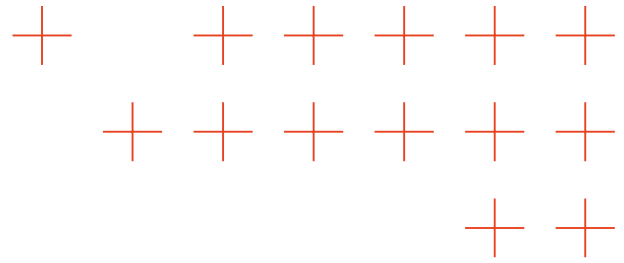


Figure 12. Buildings colored by Distance from Flood (SV-tech-04).





Drone planning (PDM-tech-04)

SmartDesk integrates data from a component that calculates optimal drone flight paths based on the information available in the current business mission.

The main objective of this functionality is to maximize the coverage and quality of data collected by drones while minimizing redundant or inefficient flight segments.

By visualizing proposed routes directly on the map, SmartDesk allows users to review flight plans before execution, ensuring that each drone mission contributes effectively.

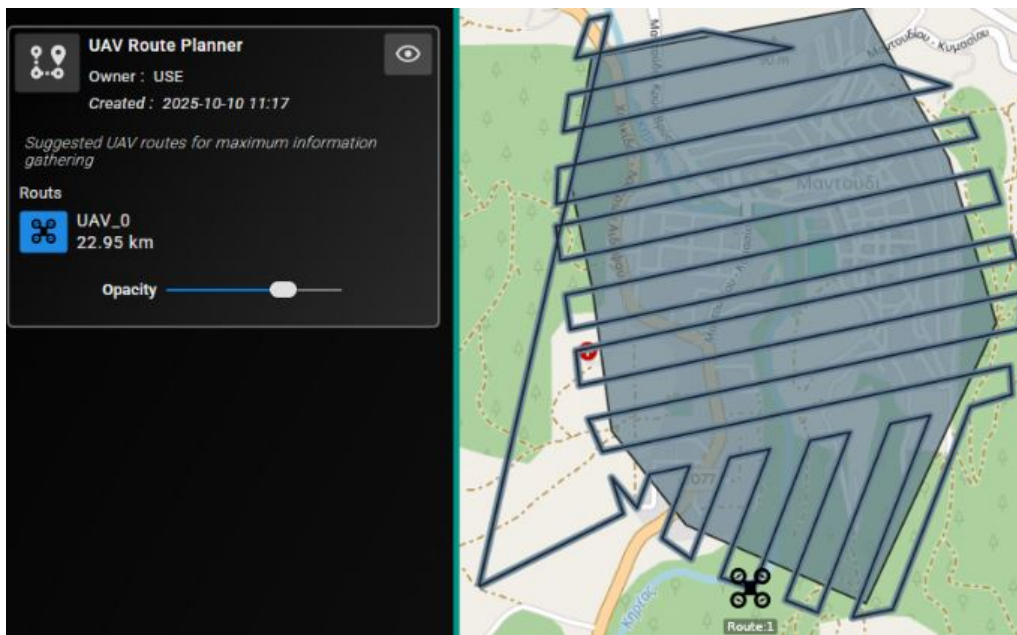
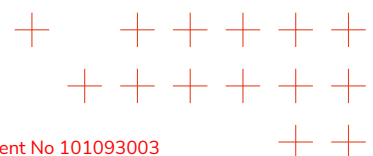
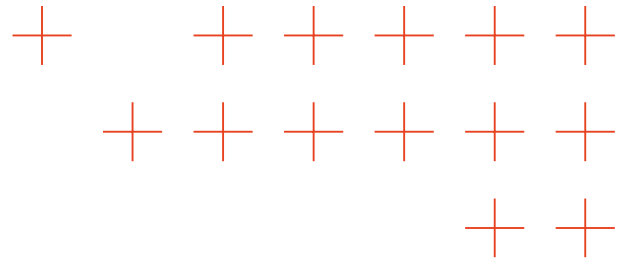


Figure 13. UAV Trajectory on the map created by Route Planner (PDM-tech-04).





3D Computer vision Photogrammetry (SV-tech-03)

This component utilizes photogrammetry to process drone-captured imagery, generating high-resolution 3D models and 2D orthomosaic maps that accurately represent the current conditions of areas affected by disasters. The core objective is to create 3D tiles from aerial image sets; however, in some cases, the available photos may not provide sufficient coverage or overlap to produce a complete 3D reconstruction. In such cases, the component also generates a 2D orthomosaic a georeferenced map built from the same set of drone images.

Using SmartDesk, users can interact with both visualization outputs: 3D tiles are viewed through a Cesium-based web viewer integrated into the application.

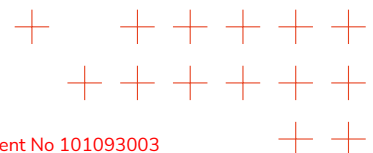
2D orthomosaic are provided as KMZ packages, containing tiled image data that enable smooth zooming and efficient memory use by loading only the required tiles during navigation.

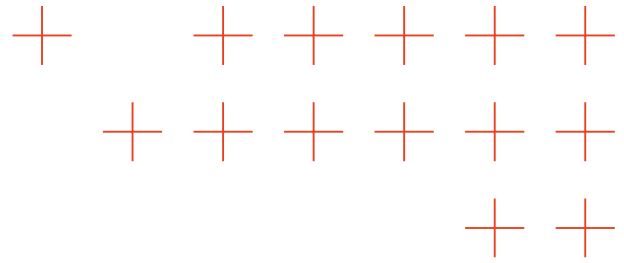


Figure 14. 3D reconstruction from drone imagery displayed in a Chrome window via SmartDesk (SV-tech-03).



Figure 15. 2D orthomosaic generated from drone images and visualized directly in SmartDesk (SV-tech-03).





Decision Support Service for Remote Sensing (PDM-tech-o6), Satellite-image-based Flood and Burnt Area Processors (TFA-tech-o8 and TFA-tech-o9)

Some components of the TEMA platform are designed to operate not only within the context of a specific business mission, but also as standalone API services. This allows users to access them at any time to obtain additional situational information for example, to decide whether initiating a new mission is necessary.

Among these services are the Decision Support Service, the Satellite ImageBased Flood Processor, and the Burnt Area Processor.

SmartDesk provides an interface for direct interaction with these services, enabling users to submit requests, monitor processing status, and visualize the analytical results within the same application environment.

SmartDesk receives data from these analytical services in various formats, including GeoTIFF, GeoJSON, and plain-text alert messages.

Decision Support alerts originate from National Civil Protection Services or Meteorological Agencies, providing real-time updates on weather conditions and potential hazards.

This multi-format data integration enables SmartDesk to combine automated analytical outputs with authoritative national warnings, ensuring comprehensive situational awareness for users.

The application displays all outputs received from these services both textual messages and geospatial map layers in an integrated visualization environment.

In addition, the application presents satellite overpass information, allowing expert users to analyze data used in processing.

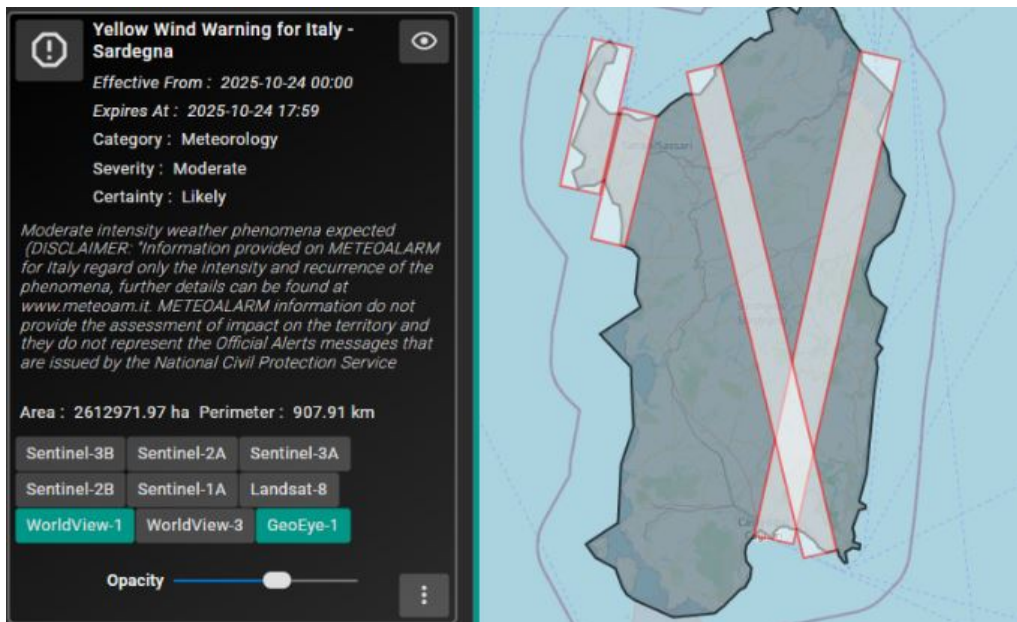
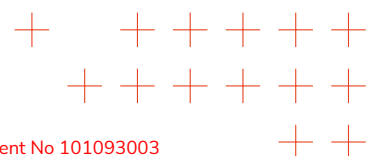


Figure 16. Decision Support output: warning message with highlighted affected area on the map (PDM-tech-o6).



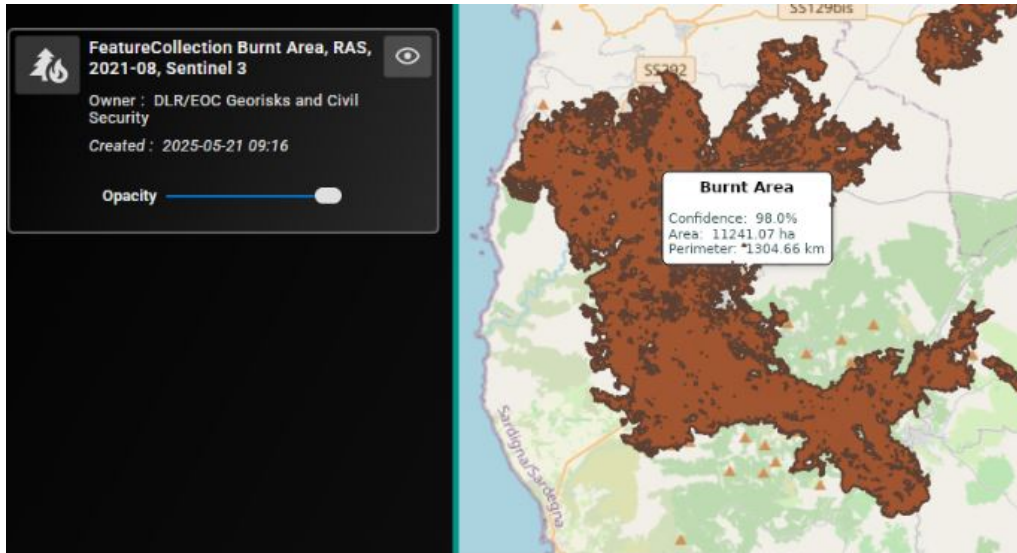
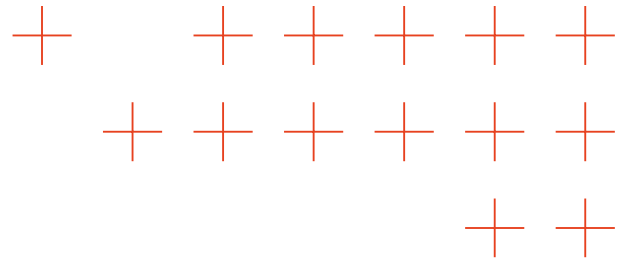


Figure 17. Burnt Area Processor output visualized in SmartDesk (TFA-tech-09).

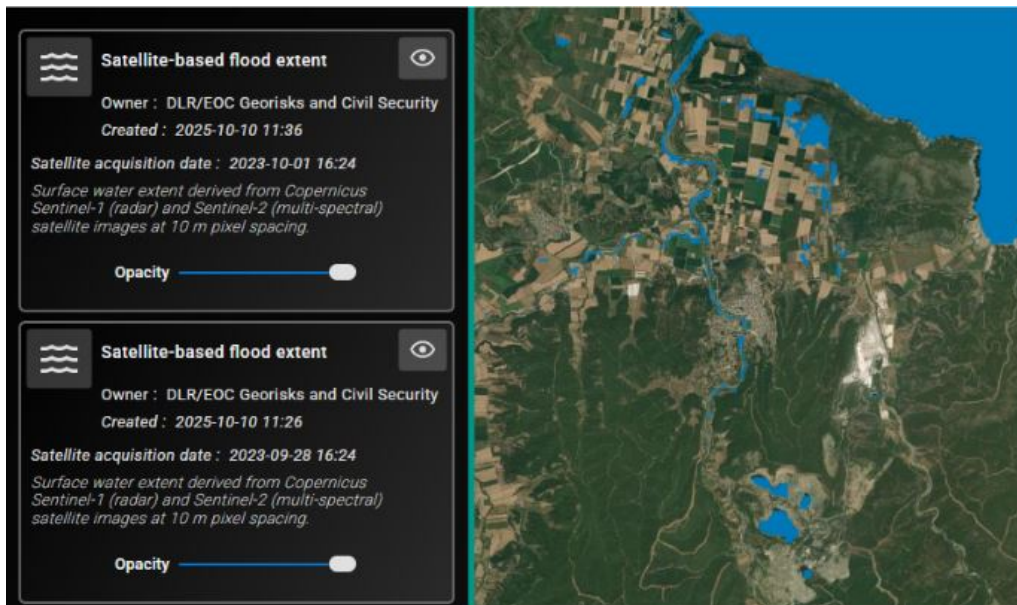
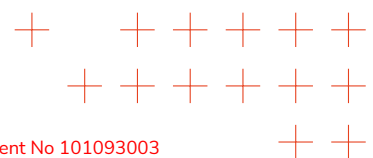
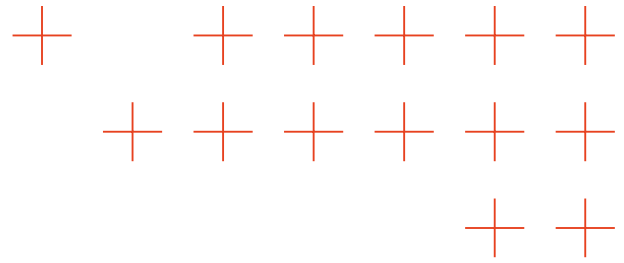


Figure 18. Flood extent map displayed in SmartDesk (TFA-tech-08).





Information fusion (PDM-tech-05)

This component is designed to aggregate data from multiple sources, combine them using advanced fusion algorithms, and produce a new probabilistic map where each pixel represents the likelihood of an event occurring at that specific location.

While this type of information may not be directly relevant to end users, SmartDesk provides visualization capabilities for this data as a dedicated map layer.

This allows developers, analysts, and advanced users to inspect the input used by other components that rely on these results for example, Geospatial Analytics and Drone Route Planner modules.

By making these intermediate data layers accessible, SmartDesk enhances transparency and supports validation of the workflow within the TEMA platform.

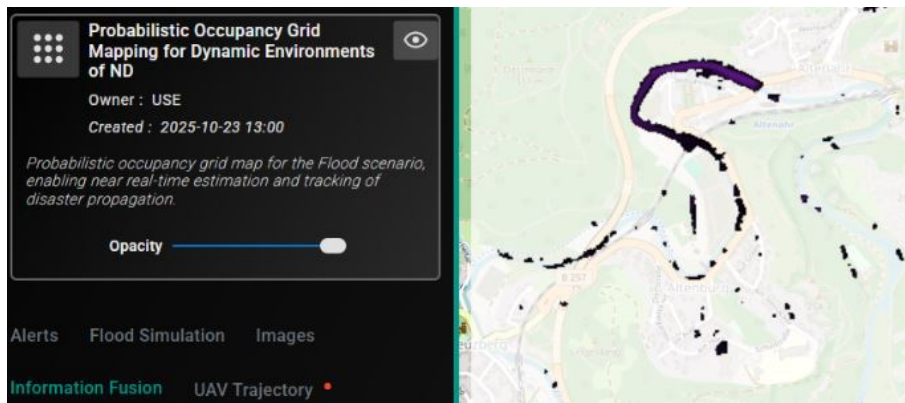


Figure 19. Probabilistic occupancy grid map for the Flood scenario disaster propagation (PDM-tech-05).

In addition to generating probabilistic raster maps, this component also produces vector map layers in GeoJSON format, containing detected objects such as people and vehicles identified in drone imagery. These vector layers allow users to visualize the positions of detected entities directly on the map.

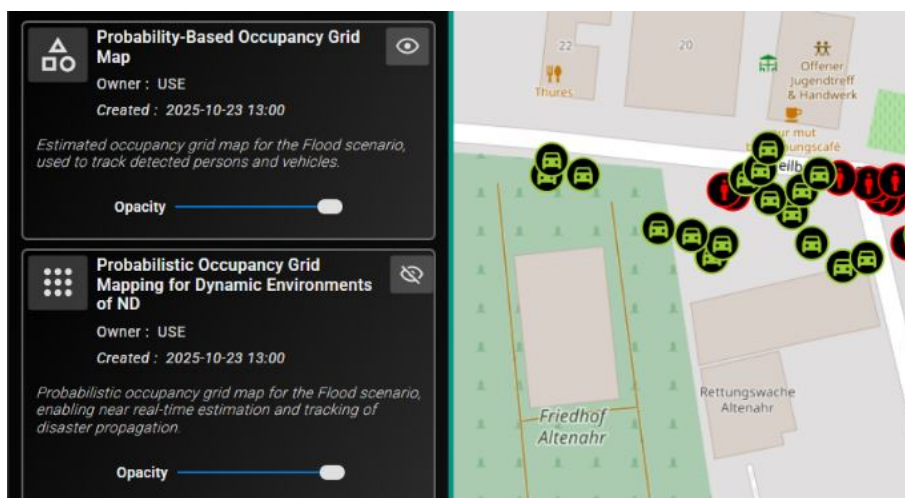
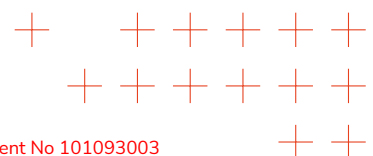
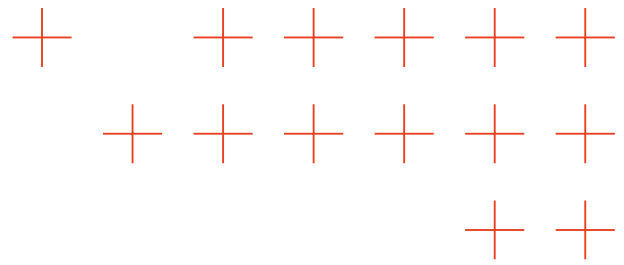


Figure 20. Probabilistic occupancy grid map for the Flood scenario detected persons and vehicles (PDM-tech-05).





3.1.9. Integration of Legacy Agency Data and Interoperability

The TEMA platform is designed to handle critical infrastructure data through a flexible integration approach that balances operational relevance with strict data privacy.

- **User-Driven Integration:** Both the SmartDesk and the XR Viewer empower disaster agencies to manually import their own data layers, such as GeoJSON marking mission-specific objects or existing local databases like power grids, cadaster information, and land parcel boundaries.
- **Privacy and Sovereignty Strategy:** Within the TEMA Cloud environment, sensitive critical infrastructure data is not stored centrally to address the high-level security concerns of national agencies. Instead, the project provides standardized interfaces that allow these "private" layers to be integrated at the user/client level. This ensures agencies can utilize their most sensitive data within a secure, local environment without compromising platform-wide privacy standards or requiring project-wide disclosure of classified infrastructure locations.

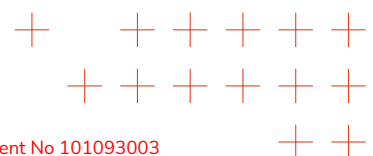
3.1.10. SmartDesk tools

Although the TEMA platform provides a vast amount of information, end users still require additional tools commonly found in geospatial applications. SmartDesk addresses this need by offering supplementary functionalities that are not directly tied to business missions or other platform components but are nevertheless essential for users.

This section presents the main internal SmartDesk components, whose primary purpose is to enhance the user experience and support system developing and testing, ensuring smooth operation and effective interaction with the platform.

Weather tool / reports

Weather reports allow users to see forecasts around the area of operation. This is important for decision making, as it allows users to see what kind of weather situation there is going on and what will be going on soon. SmartDesk can use multiple weather information providers, currently it uses Open-Meteo to provide all real-time data.



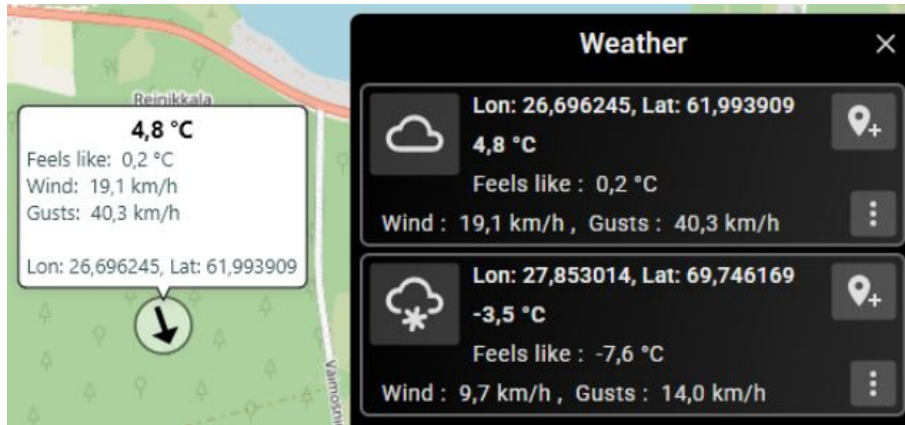
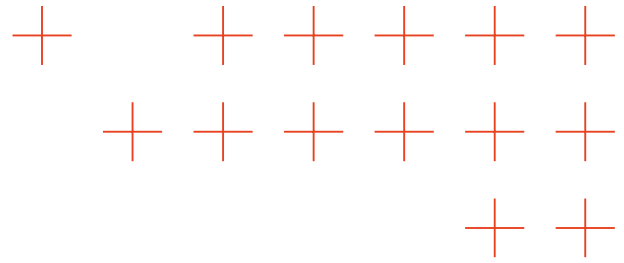
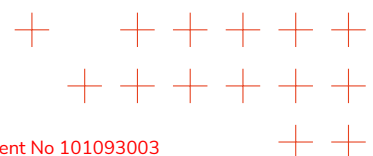
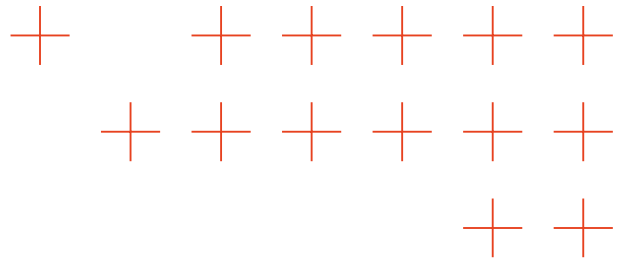


Figure 21. Weather tool in use. Arrow shows the direction of the wind, while the data is shown on both the active arrow and on a weather tool panel.

Users can select locations from the map by directly marking a location or by using the weather tools location search bar. Locations can be deleted from the list, whenever they are no longer needed. The focus here is to allow users to get accurate weather reports from multiple locations.

The data is updated once it is called by SmartDesk. Later, it is meant to update itself regularly based on user settings. This would allow the application to be accurate for indefinitely.





Drawing tools (WIP)

The drawing tool enables users to mark specific areas, targets and even mission progression plans for themselves and others. Users can draw their plans and notes for others to see. It can be used to help operatives in the field to locate important objects or check areas the other user has marked, for example from the drone view.

The tool allows users to select the area they want to crop from the original image, but its not necessary if they want to use the whole picture. The tool only has basic functionalities, such as select area for cropping (dashed line), line and rectangle drawings, eraser, undo, redo, text input, line width and color selection buttons. The save button opens dialogue where the user can select the desired path to save the image.

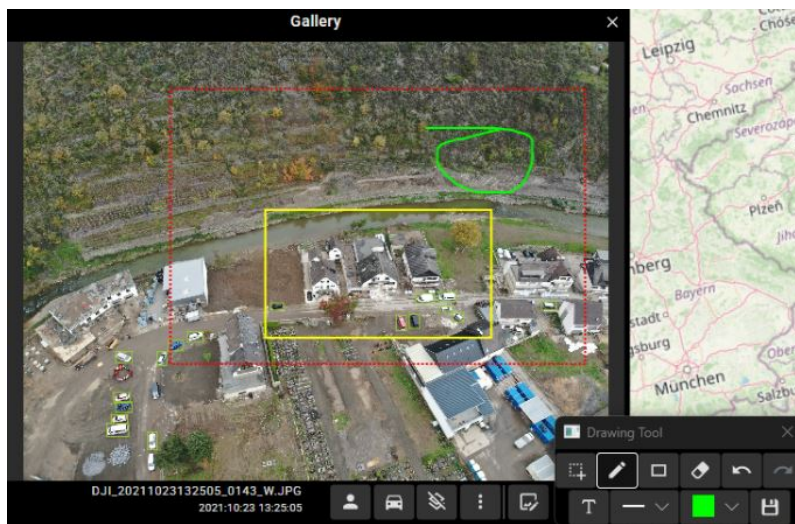


Figure 22. Drawing tool in use.

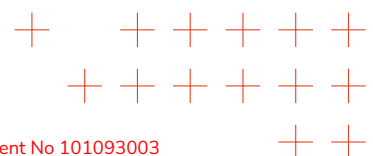
The tool adds grayscale TEMA-logo as a watermark while saving.

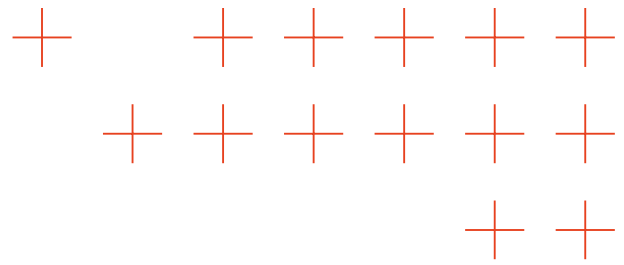


(a) Current watermark, at the bottom left corner of saved image.



(b) Saved output of the tool.





Map layers and areas

Map layers are meant to show areas with different information. For example, terrain data, elevation, satellite images, and areas with landowner data that show the property's identifier layer. This allows authorities to contact the right personnel about the situation at hand. Most countries have their own map providers, so SmartDesk is designed to support multiple different formats. OpenStreetMap is the base map provider for general areas and roads. It is community hosted and updated, bringing general use maps for all countries and partners. OpenTopoMap provides general topography for all countries in similar way to OpenStreetMap. World Imagery (Esri) provides satellite imagery for more precise visualization. Finland has Maanmittauslaitos (eng. National Land Survey of Finland (NLS)), which provides actively updated maps for both public and private uses. They also provide property codes and borders, which SmartDesk can display on top of other map layers.

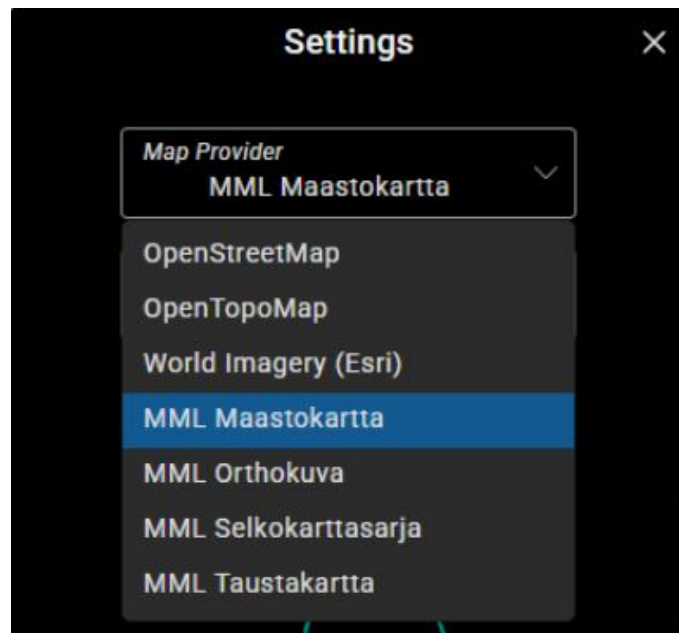
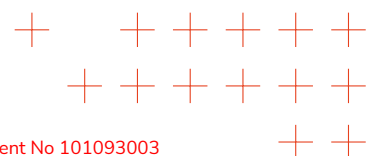
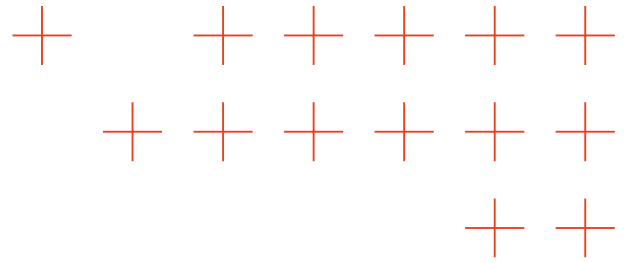


Figure 24. Map layers are provided by partners and open sources. Here is an example of Finland's Maanmittauslaitos layers, which each provide different use cases and data.





Measuring tools

SmartDesk includes measuring tools for both area and distance. The basic tools allow estimates to be created by the users directly on top of the map layers. These tools are being updated as they are tested to give both more accuracy and editing possibilities.

Line measuring tool allows estimating distances between two or more points.

Area measuring tool allows estimating both lines and area, since it does include the possibility to see distance between each point.

The points can be removed and lines edited with editing tool selected.

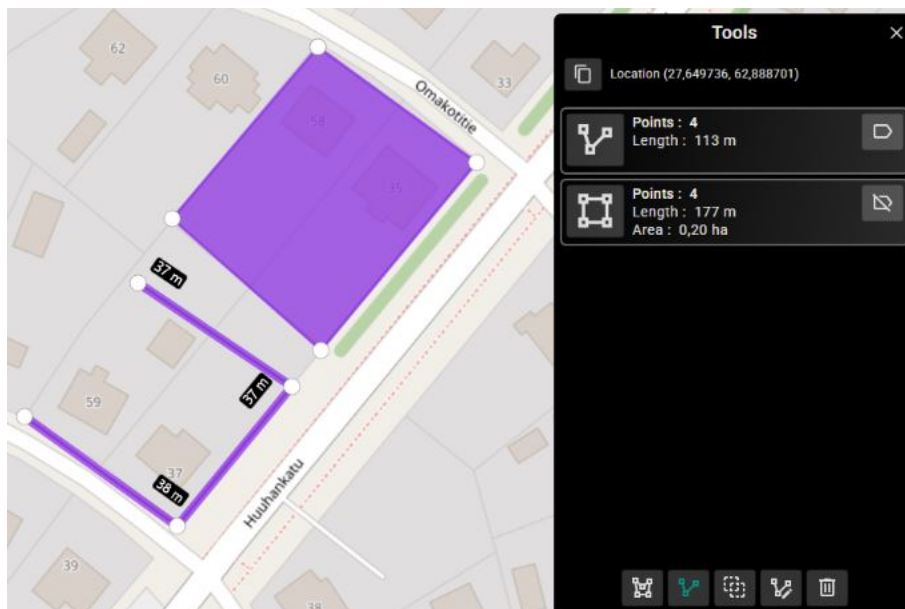
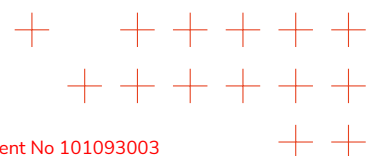
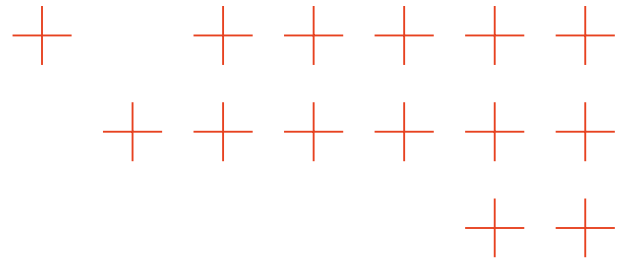


Figure 25. Measuring tools allow estimating distances and areas with multiple points. There is an option to toggle the distance between each dot. Full length and the editing tools for the measurements are visible on the right-side panel.





Training materials

Training materials are created for users to test the work in progress tools. Later, when the application is nearing completion, a complete training manual will be created to help users learn to use the SmartDesk. There is a plan to create an openable manual (PDF) inside SmartDesk, which could be opened to a new window and used at the same time as the SmartDesk software.

Feedback (SmartDesk)

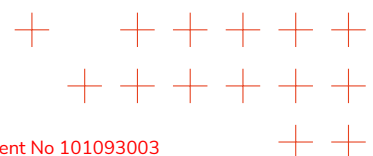
End user feedback is collected through test sessions, end user training and pilot tests. SmartDesk is upgraded and made more user-friendly based on the conversations with end users. Feedback is generally collected by taking notes during training sessions and conversations, since it has been more productive and end users give more detailed feedback that way compared to polls or questionnaires.

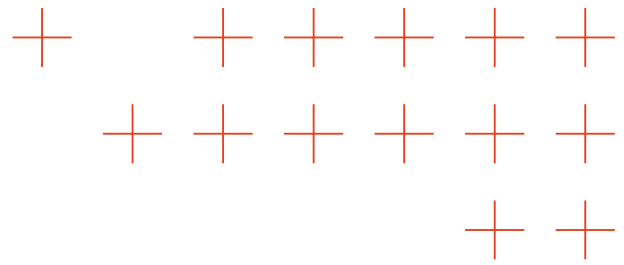
3.1.11. Future Development and Enhancements

The primary focus of ongoing SmartDesk development is to enhance the integration of existing components based on feedback collected during testing sessions and pilot exercises. Another key objective is to provide first responders with as much actionable information as possible from national services, data providers, and other open sources, ensuring that the platform supports their daily operational practice and decision-making processes.

Additionally, SmartDesk development continues to improve tools for working with data generated directly within the application, drawing on user experience and feedback from project partners representing first responders and operational users.

Therefore, it is crucial to seamlessly integrate these services into the system and ensure smooth operation, while allowing users to access all necessary tools within a single application, maximizing efficiency and usability in operational scenarios.





3.2. XR Viewer Technology (Northdocks)

3.2.1. Defining Extended Reality (XR)

Extended Reality (XR) is an umbrella term that encompasses Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). These technologies modify a user's perception of reality by merging the real and virtual worlds or by creating entirely computer-generated environments.

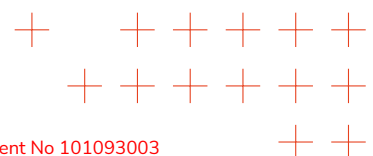
Virtual Reality (VR) immerses a user in a completely artificial, digital environment, typically through a head-mounted display (HMD) that blocks out the real world. In VR, users can interact with simulated objects and scenarios as if they were physically present.

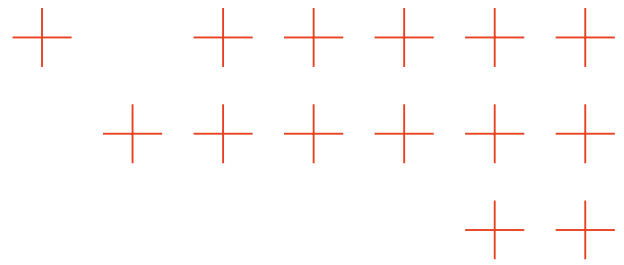
Augmented Reality (AR) overlays computer-generated information - such as images, text, or 3D models - onto the user's view of the real world. This is often achieved through smartphones, tablets, or specialized glasses. The fundamental premise of XR is to present data and information not as abstract figures on a screen, but as tangible, spatial elements with which a user can intuitively interact.

3.2.2. The Role of XR in Enhancing Situational Awareness

In high-stakes fields like Natural Disaster Management (NDM), situational awareness - a clear and accurate understanding of the operational environment - is paramount. Traditional methods of data visualization, such as 2D maps, dashboards, and charts, are essential but have limitations. They require a significant cognitive load to translate abstract representations into a mental model of a real-world, three-dimensional space.

XR technologies offer a paradigm shift in how this information is consumed. By presenting geospatial data within an immersive 3D environment, XR can drastically reduce this cognitive load. A decision-maker can, for instance, "stand" in a virtual representation of a city and see the projected water levels of a flood firsthand, rather than interpreting contour lines on a map. This direct, experiential form of data consumption leads to a more intuitive and rapid understanding of spatial relationships, risks, and potential impacts. This capability is crucial for training, allowing responders to experience realistic scenarios in a safe environment, and for planning, where teams can collaboratively explore and discuss response strategies around a shared virtual or augmented model of the affected area.





3.2.3. Challenges and State-of-the-Art

The application of XR in NDM is a growing field, but it is not without its challenges. A primary hurdle is the **data pipeline**: converting vast and heterogeneous geospatial datasets into optimized, performant 3D assets that can be rendered in real-time on resource-constrained hardware (such as standalone VR headsets) is a complex technical task. Furthermore, ensuring the **accuracy and geodetic correctness** of these visualizations is critical for them to be useful for professional decision-making.

The state-of-the-art is moving towards cloud-native platforms and game-engine-based solutions (like Unreal Engine or Unity) that can leverage specialized plugins for handling geospatial data. These platforms offer the high-fidelity rendering and interactivity necessary for creating convincing and useful XR experiences. However, achieving a seamless, rapid workflow from raw data to immersive visualization - especially for on-the-fly, in-field applications - remains a significant area of active development and research.

3.2.4. Market Comparison and Differentiation

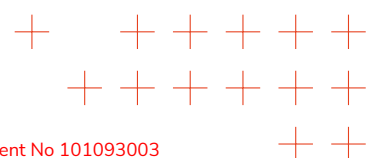
While standard market solutions for geospatial visualization and Geographic Information Systems (GIS) exist, the TEMA visualization layer is uniquely engineered to address the specific "extreme data" challenges of Natural Disaster Management (NDM) that often exceed the operational capacity of traditional tools.

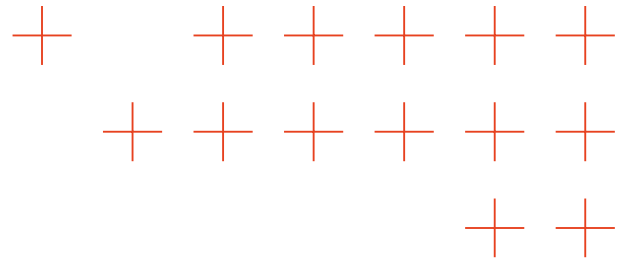
SmartDesk vs. Professional GIS (e.g., QGIS, ArcGIS): Traditional desktop GIS platforms are designed for comprehensive spatial analysis and often require significant manual intervention for data cleaning, reprojection, and layer styling. In time-critical emergency scenarios, this manual complexity can lead to information overload and delayed response. Smartdesk has the following characteristics:

- **Event-Driven Architecture:** Unlike standalone GIS tools, the SmartDesk is integrated into an event-driven ETL pipeline powered by the FIWARE NGSI-LD Context Broker. This ensures that as soon as new drone imagery is processed or a fire simulation is updated, the changes are pushed to the viewer via a SignalR-based real-time connection with sub-second latency.
- **Automated Insight Extraction:** While generic tools display raw GeoJSON or Raster data, the SmartDesk visualizes "actionable intelligence" derived from TEMAs analytical building blocks. This includes automated risk-level color-coding based on Euclidean distances from evolving hazard fronts, a process that is often a manual, multi-step geoprocessing task in standard GIS.
- **Computational Efficiency:** TEMA leverages Dask for parallel and distributed processing of "extreme" datasets, achieving near-linear speed-ups (e.g., reducing fire risk computation from 40s to 8s) that traditional single-threaded desktop GIS cannot match.

XR Viewer vs. Conventional 3D Visualizers: Most 3D visualization solutions used in emergency training rely on "pre-baked" environments or static 3D models. The TEMA XR Viewer advances the state-of-the-art through several technical breakthroughs:

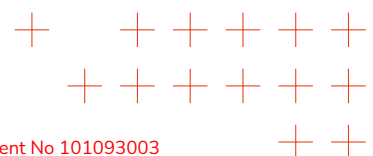
- **Runtime Mobile Integration:** Standard mobile-focused game engines often lack native support for professional geospatial formats. TEMA developed a custom plugin to enable the runtime integration of professional GeoTIFF and 3D Water Tiles directly on standalone mobile Head-Mounted Displays (HMDs).

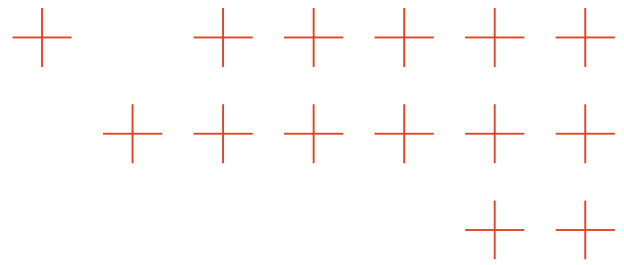




- **Geodetic Precision:** Unlike many consumer-grade VR viewers, the XR Viewer utilizes the Cesium for Unreal plugin to maintain geodetic correctness and WGS84 coordinate consistency across global-scale 3D terrain.
- **Reduced Cognitive Load:** By enabling responders to virtually "stand in the disaster area," the system transforms abstract 2D map data into "experiential intelligence". This provides a qualitative leap in situational awareness regarding spatial and temporal dynamics compared to the interpretation of static 2D contour lines.

In summary, the TEMA visualization layer is not merely a display tool but an operational interface for a high-performance cloud-to-edge continuum, providing a unified "Human-in-the-loop" decision support system that outperforms fragmented legacy systems in speed, scalability, and situational clarity.





3.2.5. The XR Viewer in TEMA

Project Context and Functional Objectives

Within the TEMA project, the XR Viewer serves as the primary interface for immersive visualization. Its functional objective is to translate the analytical outputs from other TEMA components into a coherent, interactive, and easily understandable 3D scene. The technical foundation of the viewer is **Unreal Engine**, chosen for its advanced rendering capabilities and robust support for cross-platform development. Geospatial functionality is powered by the **Cesium for Unreal** plugin, which provides a high-accuracy, global-scale 3D globe and the necessary tools for streaming and rendering geospatial datasets. This architecture supports the viewer's core functionalities, including a tabletop scenario builder, support for multiple environments (predefined worlds and a global Google Earth integration), and an Augmented Reality (AR) mode for collaborative planning.



Figure 26. Users can place objects to construct tabletop training scenarios within various 3D environments.

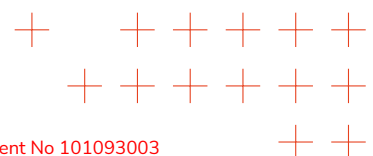
Data Integration and Technical Challenges

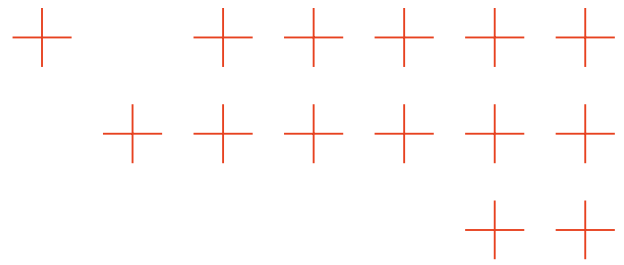
A central task of the viewer is to ingest and visualize data from various TEMA partners at runtime, a process that has presented significant technical challenges. The primary goal is to create a seamless data pipeline from partner-provided simulation outputs to an immersive visualization, without requiring offline pre-processing.

The project partner Nelen & Schuurmans delivers flood simulation datasets in specialized formats, GeoTIFF and 3D Water Tiles. Each format necessitates a tailored processing approach to ensure accurate integration and analysis, as we will show below.

GeoTIFF Integration: The initial challenge was that standard GeoTIFF libraries and Unreal Engine plugins lack support for the Android operating system used by standalone VR headsets. Furthermore, Unreal Engine's standard method for projecting textures, deferred decals, is incompatible with the Vulkan rendering API essential for mobile performance. The solution required a dedicated effort to manually compile the **GDAL and libgeotiff libraries for Android** and integrate them into a custom engine plugin. This enables the application to read the GeoTIFF's pixel data and geospatial metadata directly on the device. Work is ongoing to develop a custom mesh-based projection system to accurately overlay this data onto the Cesium 3D terrain.

3D Water Tiles: While the .b3dm tile format could be loaded, it lacked any material information, causing it to render as a plain white surface. Additionally, a significant coordinate mismatch required a manual height offset of 50 meters to align the water surface with the terrain. Addressing





this requires ongoing collaboration with partners to either include styling information in the data or to develop a system for applying materials and correcting the coordinate transformations at runtime.

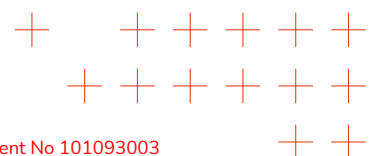
These issues highlight the core challenge of the XR Viewer's development: bridging the gap between professional geospatial data formats and the real-time rendering pipelines of mobile-focused game engines.

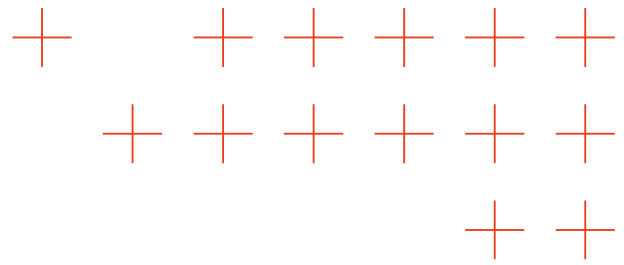
Hardware and Platform Strategy

Portability and ease of use are paramount for a tool intended for emergency management. To meet this requirement, the primary development target for the XR Viewer is standalone VR headsets, such as the PICO 4 Ultra series. The Pico 4 Ultra Enterprise features a Qualcomm Snapdragon XR2 Gen 2 processor paired with 12GB of RAM and 256GB of storage, enabling high-performance VR and MR applications with support for up to 8K video decoding and a 90Hz refresh rate. Its display system includes dual 4K+ LCD panels at 2160x2160 resolution per eye, pancake lenses for a 104° field of view, and advanced sensors like stereo 32MP passthrough cameras and a depth sensor, complemented by Wi-Fi 7 connectivity and a 5700mAh battery for extended enterprise use. This strategic decision eliminates the dependency on powerful, stationary PCs and cumbersome tethering cables, ensuring that the system can be easily transported and deployed in a variety of settings. The application is packaged as a standard Android application (APK), facilitating straightforward installation and operation. This mobile-first development approach ensures that the architecture remains optimized for performance on resource-constrained devices and extends naturally to other mobile platforms like tablets and AR-capable smartphones.



Figure 27. The XR Viewer is designed for easy use with standalone VR headsets, making it highly portable for training and field applications.





3.2.6. Key Developments and Implementation

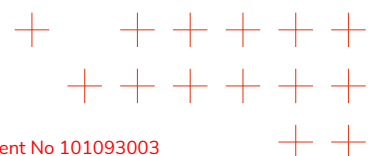
Immersive Flood Visualization

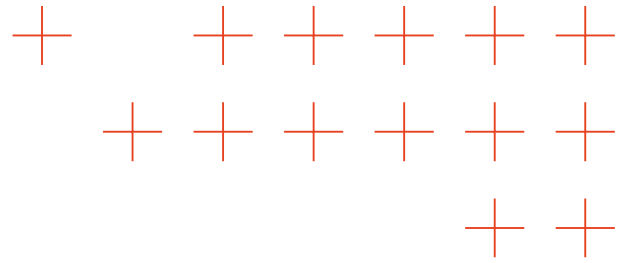
A key use case for the TEMA project is the visualization of flood events. The motivation is to provide an immersive and intuitive way to understand the impact of rising water levels, enabling faster and more informed decision-making.

The initial implementation was a First Prototype featuring a simple, flat 2D water plane with a material shader. The height of this plane could be manually adjusted, providing a rough but effective impression of the flooding extent in a given area. This prototype served as a crucial first step for validating the concept with decision-makers and gathering feedback.



Figure 28. First prototype of the flood visualization using a simple water plane with adjustable height to demonstrate the concept.





Integration of Partner Datasets (Nelen & Schuurmans)

A major development effort focused on integrating real-world flood simulation data from project partner Nelen & Schuurmans (NS). The goal, defined in collaboration with the BRK Pilot trial team, was to visualize a 3D model of the most affected area in Ahrtal, Germany, with an overlay of the NS water propagation model showing water levels at their peak. The collaborative process and the technical solutions for handling GeoTIFF and 3D Water Tiles are detailed in Section 4.2.

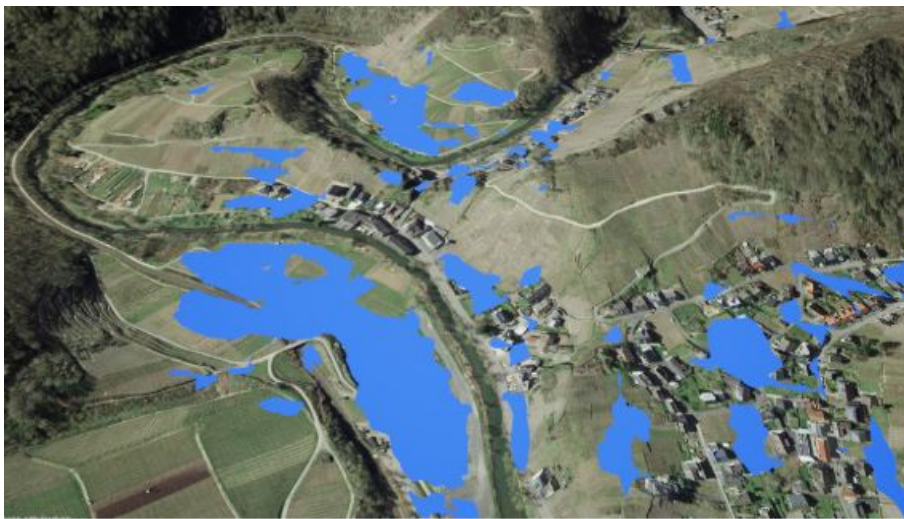
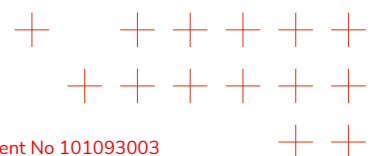
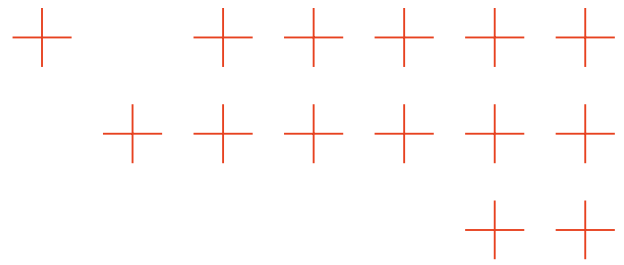


Figure 29. Initial successful loading of the 3D Water Tiles from Nelen & Schuurmans after applying a basic material and a height offset.





Runtime GeoTIFF Integration

The ability to load GeoTIFF files at runtime on a mobile device is a critical technical achievement of this work package. After evaluating multiple approaches (Texture2D, Cesium Raster Overlay, 3D Tiles), the decision was made to pursue a custom solution based on loading the file as a Texture2D. The primary obstacle was the lack of Android support in existing geospatial libraries for Unreal Engine.

After a significant development effort, a breakthrough was achieved: a custom plugin was created that successfully integrates a self-compiled, Android-compatible version of libgeotiff. This allows the application to open a .tif file from the device's storage and load its image data into an Unreal Engine texture at runtime. The current focus is on extending this functionality to read the embedded georeferencing data and use it to correctly position and project the texture onto the 3D globe.

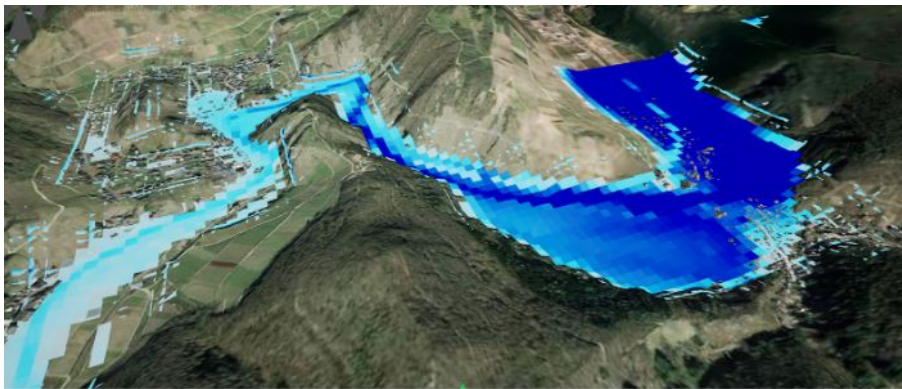
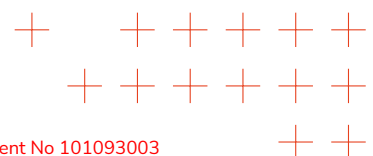


Figure 30. Visualization of the ongoing work on GeoTIFF integration, testing different loading and projection methods.

Additional Tools for Situational Awareness To enhance the utility of the viewer for planning and analysis, several additional tools were implemented:

Icons for Critical Infrastructure: Users can place markers to denote critical infrastructure such as power stations, gas stations, hospitals, and police stations, providing essential context during a scenario.

Measure Tool: A simple tool was developed to allow users to measure distances within the 3D environment, aiding in logistical planning and risk assessment.



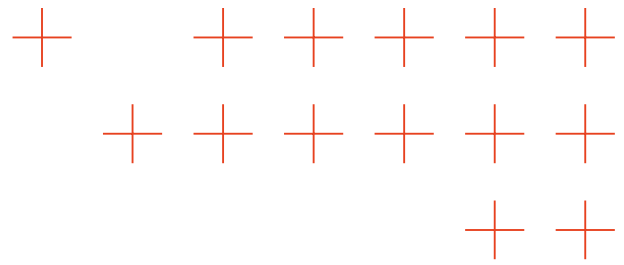


Figure 31. Markers for critical infrastructure can be placed on the map to enhance planning.

3.2.7. Conclusion and Next Steps

Impact for the TEMA Project

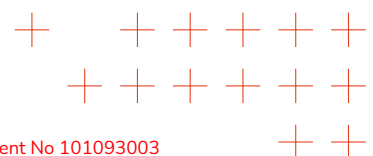
The TEMA XR Viewer represents a significant advancement in the project’s visualization capabilities, offering a tangible impact on the effectiveness of emergency management. By embedding realistic flood scenarios within an interactive VR/AR planning tool, the viewer moves beyond abstract data representation to provide true experiential intelligence. The ability for decision-makers to "stand in the flood" or view an evolving crisis from a strategic, top-down perspective offers a qualitative leap in situational awareness. This immediate, intuitive grasp of the spatial and temporal dynamics of an event is designed to foster a stronger awareness of risks, which in turn can lead to faster and more confident reaction times when seconds count.

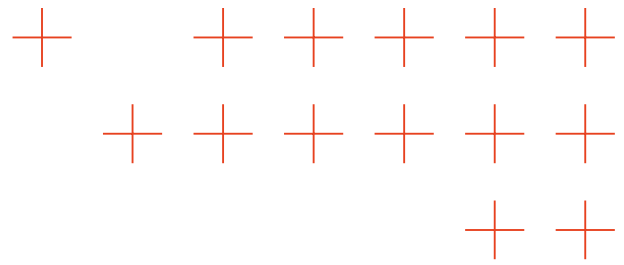
Furthermore, the impact of the XR Viewer extends across the entire disaster management life-cycle. It serves as a powerful educational tool for training both professional first responders and volunteer organizations like youth fire brigades in realistic, yet safe, simulated environments. In an active crisis, it can function as an early warning system by visualizing predictive models of a hazard’s progression. After an event, the same tool can be used for post-event analysis, allowing stakeholders to reconstruct and learn from past incidents to improve future resilience. By fulfilling these multiple roles, the XR Viewer becomes a cornerstone of the TEMA platform, empowering users with a holistic and deeply insightful understanding of emergency situations.

Future Development Roadmap

While significant progress has been made, the future development of the XR Viewer is focused on maturing the prototype into a fully operational and robust tool. The roadmap for the next development phase is guided by three core principles: accuracy, speed, and usability.

A primary focus will be the deepening of **partner data integration**. This involves finalizing the technical pipeline to seamlessly ingest and visualize complex datasets, such as the flood models



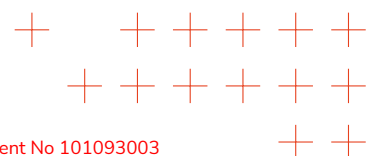


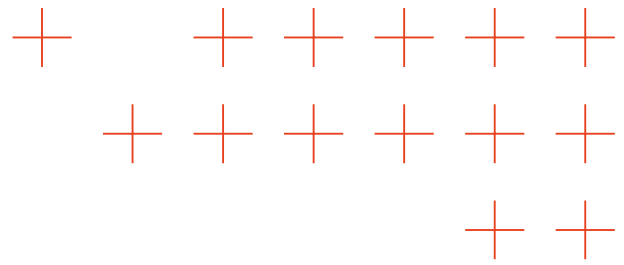
from Nelen & Schuurmans. A critical component of this effort is the establishment of a rigorous **validation process** to ensure that the visualized data is a high-fidelity representation of the source model. This guarantees that decision-makers can trust the accuracy of the information presented.

Concurrently, there will be a major effort to create a **fast data-to-visualization** pipeline. The objective is to drastically reduce the latency between the availability of a new dataset and its visualization within the XR Viewer, shortening the turnaround from days or weeks to a matter of minutes or hours. This is essential for the tool to be effective in near-real-time operational scenarios. This work will also involve creating both low-resolution models for rapid, large-scale overviews and high-resolution models for detailed analysis, balancing performance with the need for precision.

Finally, significant improvements in **usability and workflow optimization** are planned. This includes streamlining the data import process, particularly by implementing a reliable file picker that functions across different mobile and tablet devices. By focusing on these key areas, the TEMA XR Viewer will evolve into an even more powerful and reliable instrument, ultimately fulfilling its goal of empowering decision-makers with immersive, accurate, and timely flood awareness tools.

A broader evaluation of the XR Viewers role within the TEMA visualization ecosystem is presented in Chapter 5.





4. Integration into the TEMA Architecture

SmartDesk and the XR Viewer are integrated into the TEMA ecosystem as complementary visualization systems that connect analytical results with operational decision-making. Both applications rely on the Orion Context Broker to exchange and synchronize data with analytical and simulation components developed in WP4. This section provides an overview of their combined integration approach and summarizes validation outcomes.

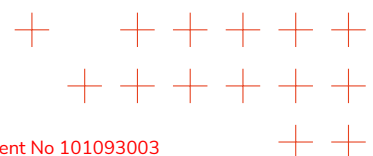
4.1. Integration of SmartDesk (KAMK) and XR Viewer (Northdocks)

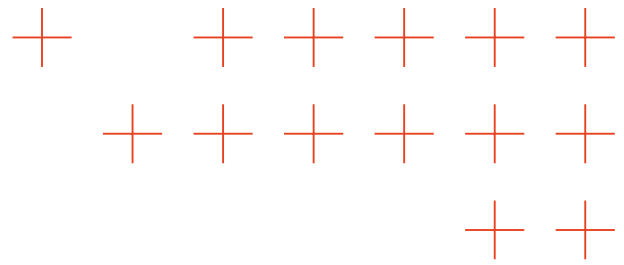
The two visualization tools are built on shared principles of interoperability and open standards. SmartDesk acts as the main operational hub for data access, analysis, and mission coordination, while the XR Viewer provides immersive visualization of the same data to enhance spatial understanding and communication.

Both systems use standardized formats such as GeoTIFF, GeoJSON, KML, and 3D Tiles, ensuring smooth data transfer between the Context Broker, SmartDesk, and the XR Viewer. SmartDesk retrieves data directly from the Orion Context Broker, displaying simulation results, alerts, and analytical layers in real time. These datasets can then be exported or synchronized to the XR Viewer for three-dimensional or immersive analysis. The XR Viewer leverages the same coordinate reference system (WGS84) as SmartDesk, guaranteeing spatial consistency between both environments.

In practice, SmartDesk is employed for operational control and planning, where users interact with dashboards, mission layers, and analytical results. When detailed spatial inspection or scenario exploration is needed, users can transition seamlessly to the XR Viewer. This workflow allows the same data to be experienced on two levels: analytical (SmartDesk) and experiential (XR Viewer), combining precision with situational depth. Data integrity is ensured through authenticated access, logged transactions, and consistent metadata across both systems.

The integration has been designed to support both online and offline modes. SmartDesk maintains local caches for essential datasets, while the XR Viewer can operate independently in field environments without continuous connectivity. Synchronization routines ensure that datasets remain up to date once a network connection is re-established. Together, these mechanisms provide a resilient and user-centered visualization infrastructure for emergency management operations.





4.2. Validation and Use Cases

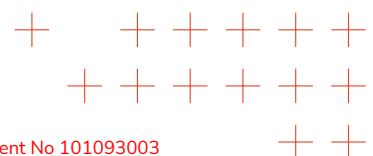
Integration and validation activities were conducted jointly by KAMK, Northdocks, and other TEMA partners. Two main use cases were applied to verify interoperability and user value: the **Ahrtal Flood Scenario** and a **Wildfire Scenario**. Both demonstrated that SmartDesk and the XR Viewer can visualize simulation outputs consistently, with complementary strengths.

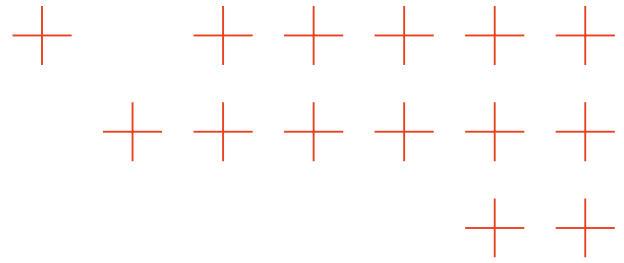
In the Ahrtal case, hydrological data from Nelen and Schuurmans were processed in PDMo2 and published through Context Broker. SmartDesk displayed hydrological layers, hazard zones, and related alerts, while the XR Viewer projected flood depths and terrain in a 3D environment. This combination allowed users to correlate model data with real-world topography and infrastructure. The wildfire scenario extended this approach, integrating drone imagery, fire propagation models, and social media analysis. SmartDesk handled data integration and command coordination, while the XR Viewer provided intuitive 3D overviews of spread behavior and affected areas.

Validation during the BRK pilot preparation confirmed strong user acceptance. Emergency responders emphasized that SmartDesks structured interface supported decision processes effectively, while the XR Viewer improved situational comprehension and communication among teams. Lessons learned included the need for consistent metadata schemas, simplified export pipelines, and shared styling conventions across platforms. These insights informed the final integration design and will guide future updates.

Beyond the technical development detailed in this deliverable, a formal, multi-faceted evaluation of the operational impact of the SmartDesk and XR Viewer is a core objective of Work Package 6. The practical value and usability of these tools are rigorously assessed following the Trial Guidance Methodology (TGM), a structured framework ensuring results from each trial are comparable and actionable. Under Task 6.3, detailed Trial Action Plans (TAPs) were developed, including structured evaluation questionnaires consisting of 30+ questions focused on usability, decision-making support, and situational clarity, 3 of them are directly targeting the evaluation of the XR Viewer.

During the first round of 2025 pilot trials, feedback was collected from 34 senior first responders who confirmed the platform's effectiveness in reducing cognitive workload and eliminating the information silos that typically hinder NDM decision-making. A statistically significant assessment of the "Augmented Reality Immersion" scores (KPI OB3 iii) and usability metrics will be formally documented in the final reports following the 2026 operational trials (Task 6.4).





5. Conclusions and Next Steps

The completion of T5.2 and T5.3 marks a major milestone in the mission of TEMA to enhance decision-making capabilities through advanced visualization. The combined development of SmartDesk and the XR Viewer demonstrates how analytical precision, interoperability, and user-centered design can merge to support effective disaster preparedness and response. This chapter reflects on the main achievements, the insights gained, and future directions of both tools.

5.1. Key Achievements and Lessons Learned

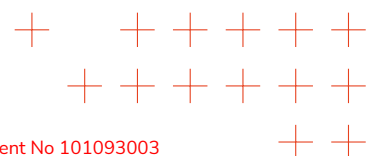
The development of SmartDesk and the XR Viewer has resulted in two mature and interoperable visualization systems that expand the analytical and operational reach of the TEMA platform. SmartDesk provides the control and monitoring capabilities required for mission planning and operational management, while XR Viewer introduces a new dimension of immersive, spatially accurate interpretation. Together, they bridge the gap between analytical data and human understanding.

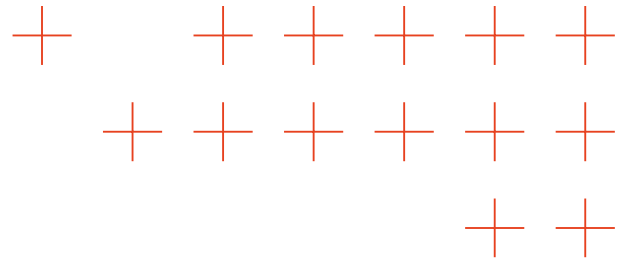
The principal achievements of T5.2 and T5.3 include:

- The successful design and implementation of two visualization systems built upon open standards and interoperable architectures.
- Seamless integration with the Digital Enabler and other TEMA components, ensuring consistent data flow between analytics, simulation, and visualization layers.
- Validation with real-world datasets from flood and wildfire scenarios, proving the operational value of the visualization tools.
- Strong focus on cross-platform optimization, enabling deployment on desktop, mobile, and XR hardware.
- Iterative development guided by end-user feedback from BRK and partner institutions, resulting in improved usability and situational clarity.
- **All KPIs** with respect to Work Package 5 have been reached.

Beyond these concrete deliverables, T5.2 and T5.3 have also conceptually contributed to the overall goals of TEMA. The work demonstrated that visualization should not be treated only as a presentation layer but as a dynamic analytical interface that enhances data interpretation and supports collaborative decision-making. By providing users with flexible tools that adapt to both analytical and experiential contexts, the project advanced the state of the art in geospatial decision-support systems.

The lessons learned throughout the process emphasize the importance of usability, performance, and trust. Interoperability challenges such as handling large GeoTIFF datasets or aligning coordinate systems across tools highlighted the value of standardized workflows. Iterative feedback from operational partners confirmed that effective visualization requires not only technical accuracy but also simplicity and relevance for field users. These insights have informed refinements of data structures, user interface design, and rendering pipelines.





5.2. Outlook and Future Work

Looking ahead, T5.2 and T5.3 will continue to refine both SmartDesk and the XR Viewer as integral components of TEMAs visualization ecosystem. Their next deployment will occur during the **BRK Pilot Trial**, where real users from civil protection and emergency management will evaluate the systems under operational conditions. This validation phase will provide critical feedback on usability, performance, and overall impact.

Future development priorities include:

- **Time-series visualization:** Implementation of dynamic flood and wildfire simulations that evolve over time to enhance situational foresight.
- **Real-time synchronization:** Closer FIWARE integration to enable live data streaming from sensors, models, and field reports into both visualization environments.
- **Hazard model expansion:** Inclusion of new risk domains such as landslides, infrastructure damage, and multi-hazard interactions.
- **Enhanced collaboration features:** Shared annotations, scenario saving, and synchronized views between SmartDesk and XR Viewer for distributed decision-making.
- **Training and education:** Use of both tools in simulation-based learning environments for emergency personnel and municipal authorities.

In the long term, the technologies developed within T5.2 and T5.3 offer strong potential for reuse beyond the scope of TEMA. The open architecture and modular structure of both systems enable adaptation to new domains such as environmental monitoring, urban planning, and infrastructure resilience. Furthermore, the integration of immersive visualization into analytical workflows has attracted interest from external partners and could form the basis for future research and commercialization efforts.

By establishing a robust visualization foundation that connects data, simulation, and human experience, T5.2 and T5.3 have laid the groundwork for the next generation of interactive, user-centered decision-support tools. The continued evolution of SmartDesk and the XR Viewer will ensure that TEMAs outcomes remain relevant, scalable, and impactful for years to come.

