User-tailored visualization of simulation and sensor data for efficient crisis management

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ABSTRACT

The availability of all relevant data in a situation report is key for efficient crisis management. The digital twin concept allows for comprehensive data accumulation, both from real-world sensors as well as augmented by simulations. However, the excessive amount and detail of data can hinder usability and discourage users or impede efficient decision making. To still benefit from such emerging technologies, user-tailored data visualization with appropriate filtering and processing is recommended. This work promotes the use of a standardized data aggregation in order to optimize customized data processing through implementation into existing platforms for crisis management. The concept is showcased for three well-established platforms with data accumulated from a standardized digital twin representation of urban critical infrastructure and emergency units. Each of the examples focuses on different facets of visualization as typically demanded by the respective target user group.

Keywords

Data aggregation, user-tailored data visualization, simulation and sensor data, crisis management

INTRODUCTION

The increasing frequency and intensity of critical situations resulting from both man-made and natural disasters require a heightened focus on security and resilience measures. A major focus of these measures is on critical infrastructure, as the failure or disruption of this infrastructure can have a significant impact, potentially leading to supply shortages and failures, thus reducing the level of public safety. Due to the highly crosslinked nature of the modern world, the shortfall of one single infrastructure provider not only has an impact on the immediate environment but might also affect other critical sectors. In particular, unanticipated interdependencies and cascading effects between different critical infrastructures may lead to the increased risk of severe disruptions (Rehak et al., 2016; Rehak et al., 2018). Therefore, a deep understanding of interdependencies and cascading effects is required in order to take targeted actions and maintain public safety.

The high level of interconnectedness of critical infrastructure also has an impact on the assessment of a critical situation: Knowledge of a single domain is often not sufficient to respond to the situation, as in many cases several sectors are involved. Nevertheless, it is crucial for decision makers to act quickly and efficiently to prevent worst case scenarios. In such situations, visualization is a key tool to break down the complexity and simplify data access and interpretation. It helps stakeholders to understand, analyse, and respond effectively to complex scenarios, leading to better outcomes and risk mitigation. Furthermore, it enables people from outside the field to gain understanding and interpretation of the situation.

Large sensor networks and shared data bases, especially when augmented by computer-aided modelling and numerical simulations, can provide useful but potentially overwhelming amounts of information about complex situations. For analyses regarding the aforementioned interdependencies and cascading effects, disentanglement and preprocessing of information is needed.

The well-known proverb “A picture is worth a thousand words” underlines the power of a visualization. However, the quality of the visualization is also crucial, as every simplified visualization always runs the risk of leading to misunderstandings and misinterpretations. In order to enhance the correct understanding and assessment of a critical situation, it is necessary to adapt the visualization to the needs of different user groups.

This paper presents the concept of a versatile processing pipeline for large comprehensive amounts of complex, interdependent data using three different visualization tools. All of them are able to highlight relevant aspects of critical situations to their respective user groups. This is made possible by the consistent use of open standards as an intermediary between data producers and consumers. The three compared tools are a representative selection of well-established tools used by different user groups in public safety. However, other visualization software could be used as well.

The chosen tools were all developed at Fraunhofer which provided easy access to necessary implementations by the authors. The *Elektronische Lagedarstellung* (ELD, engl. *Electronic Situation Dashboard*) is used extensively in the context of operations and exercises at local governments in Germany. The *Digitaler Lagetisch* (DigLT, engl. *Digital Map Table*) focuses on shared situation visualization and analysis in civilian and defense applications. The targeted user groups of the operational command software *MobiKat*® range from the command staff to the relief forces of fire and rescue services, as well as disaster managers and the police. All these user groups work on public safety from different viewpoints and have different requirements which led to these different software systems. This paper presents an approach to visualize complex data in these established software systems tailored to each user group.

BACKGROUND

The Fraunhofer Center for the Security of Socio-Technical Systems (SIRIOS) builds a research, testing and training environment based on coupled simulations of complex security scenarios. The developed co-simulation framework is presented in Martini et al. (2024). It is designed to explore and assess the impact on citizens and to be used for training purposes or in real-life situations to evaluate different counter measures to security threats. The framework provides a digital twin representation of relevant critical infrastructure sectors in an urban environment. Special attention is paid to reproducing and disclosing dynamic cascading effects between the respective sectors through a coupled simulation with defined mutual interdependencies. To this end, stand-alone modules for the simulation of several critical infrastructures are included, e.g., power, gas, water, and telecommunication grids as well as the operational dynamics of emergency response units and hazard-dependent vulnerability assessment of building structures. The framework is an ideal information source for the intended processing and visualization pipeline as it offers the ability of incorporating a large variety of heterogeneous simulation modules which are based on, e.g., engineering models rooted in physical principles, on agent- and rule-based modelling or on structural engineering analyses. Especially in conjunction with available real-life sensor data, this approach maximizes the information content deliverable by the digital twin. Thus, it can provide large amounts of interdependent data.

Naturally, each of the incorporated modules produces individual formats of output data. Utilizing well-established concepts from the *IoT* (internet of things) sector together with standardized data models proves to have versatile benefits. The Open Geospatial Consortium (OGC), a neutral and collaborative platform within the geospatial industry fostering innovation and development of open standards (van Rees, 2013), has introduced such a model:

the *OGC SensorThings API* (Liang et al., 2021). It offers a canonical way for embedding arbitrary heterogeneous modules into the framework if their entities and results can be interpreted within the respective *IoT* data model. To reach a level of data harmonization, the presented framework suggests interpreting the key entities of each infrastructure model as *Things*[1] equipped with *Sensors* which provide synthetic *Observations* from the respective simulation results to be stored on a *FROST* server instance (Hertweck et al., 2019; Fraunhofer IOSB FROST, 2023). Additionally, the interdependencies between different infrastructures can be defined on the basis of the thing representation of their respective models. Thereby, it is specified how the inter-modular information transfer required for the coupled simulation can be realized independently of the inner details of the actual simulation modules. Treating simulated and actual sensor data on an equal footing maintains the concept of the digital twin when incorporating simulation results in the accumulated data.

Each of the coupled simulation modules potentially produces an arbitrary amount of data, which might not be completely relevant in all details for the specific user demand of the digital twin framework. Thus, preselection and data aggregation are necessary for optimal, efficient use of the provided data. Assuming applications of the framework in training settings of relief units and task forces, or infrastructure managers or as aid for decision support used by decision makers, authorities, and organizations with security responsibilities, implies human users with diverse professional backgrounds. Besides appropriate preselection and aggregation, suitable and flexible visualization options of the data are therefore mandatory in order to concisely convey relevant information as efficiently as possible.

An increasing number of municipalities, service providers as well as emergency units rely on well-established digital tools like dashboards, geographic information systems (GIS) and even digital twin models to aggregate, display and analyze data. In order to seamlessly integrate the results of the co-simulation framework into such already existing eco systems and to benefit from well-rehearsed workflows for analysis and visualization of the data, providing open standard interfaces is advantageous. This is especially important for retaining an accustomed level of usability together with a low entry threshold after the introduction of new technology into a fast-paced, heterogeneous environment like crisis management. Data representation and storage as well as connecting data entities in the digital twin representation provided by the co-simulation framework relies on the *OGC SensorThings API* standard. Thus, further data processing and analysis followed by suitable visualization can, in principle, be carried out by any tool which is compatible with this *IoT* standard (Russell et al, 2018) (see figure 1). Utilizing the comprehensive digital twin representation as the central information backbone with a standardized interface to various visualization and analysis platforms facilitates additional benefits regarding resource management: Laborious tasks like complex simulation runs as well as data acquisition and aggregation need only to be performed once in a suitable, possibly remote, environment like, e.g., a high-performance computing cluster. Different user groups can subsequently access and update, if possible, specifically funneled data quickly and in parallel over their respective platforms of choice (see figure 1). Furthermore, this pipeline ensures a common and synchronous database through all involved platforms and tools. Note that an update of the common database by one tool might trigger a renewing simulation run with implications for all online tools (as indicated by the reverse arrows in figure 1).

VISUALIZATION TOOLS

In the following, the three representative visualization and processing tools, which are commonly used by the foresaid user groups, are briefly showcased. Their individual properties and features are highlighted together with accordingly customized filtering, summarizing, processing, and visualization options of the data to accomplish efficient data transfer tailored to the respective target user group.

[1] In the *OGC SensorThings API standard*, a *Thing* is an arbitrary *IoT* device or system able to provide streams of sensor data.

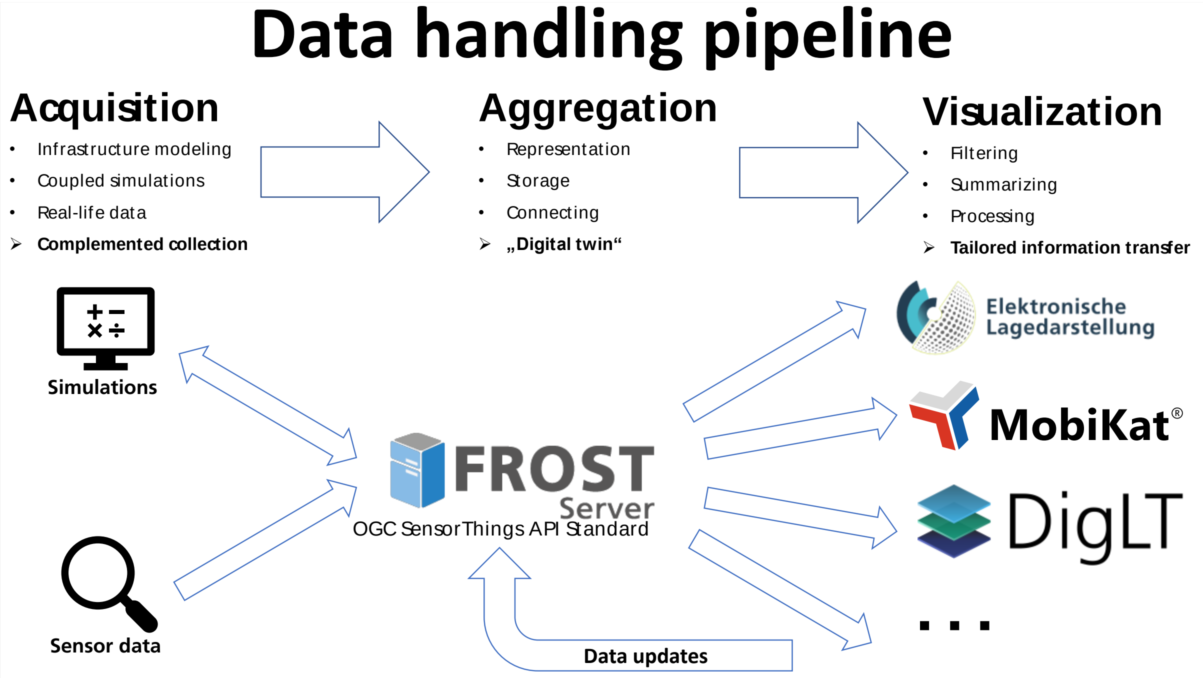

Figure 1. From data acquisition to user-tailored visualization.

ELD

The *Elektronische Lagedarstellung* (ELD, engl. *Electronic Situation Dashboard*) is a web-based information system that links a wide range of data to support decision making. One of its main purposes is to support staff work and crisis management by authorities in critical situations. The software enables the collection, management, and visualization of raw data (e.g., time series from sensors) as well as expert knowledge. The ELD is based on open standards. This allows for easy incorporation of external data sources. It demonstrates its strengths when the given data has a spatial reference as the integration of maps is one key function. Supported formats include Web Map Service (WMS) and *IoT* sensor data such as *OGC SensorThings API* (Fraunhofer IOSB, 2024).

As described in Martini et al. (2024), the proposed co-simulation framework relies on the concept of digital twins – and simulation data can be seen as sensor data. Therefore, the ELD interface to the *OGC SensorThings API* with special support for the open-source product *FROST* allows an integration and visualization of the simulation data. In general, all *Things* on a *FROST* server can be displayed in the ELD, regardless on their level of granularity. Pre-processing of all available data is therefore necessary in order to reduce the amount of data and generate a user-tailored visualization.

The ELD map relies on the concept of individual visual layers. This makes customization of the visible data easy: Layers can be overlaid to aggregate information and hidden to filter information. To this end, the complete result of the co-simulation is broken down to the results of single components. These individual results can in turn be displayed on one or more map layers. Each map layer can then be individualised by defining custom icons, different colours and further settings, e.g., line style. In addition, the use of layer groups makes it possible to preset the visualization for different user groups.

One group could include all data on the public electricity grid for an infrastructure operator, from substations to individual power lines and consumers. Another could contain relevant data about the public networks to provide decision-makers with a holistic view of the situation (see figure 2). This includes knowledge of the supply status per building as well as cumulative statistics per infrastructure. In addition, affected buildings are coloured in order to quickly identify relevant areas.

During the use of the ELD, other software requirements were identified, such as real-time map updates. The implementation of these features is planned for the future. In summary, all results produced in a coupled co-simulation can be integrated into the ELD. However, the data is aggregated and filtered to produce a high-level visualisation and to provide easy access to the data for authorities and decision makers.

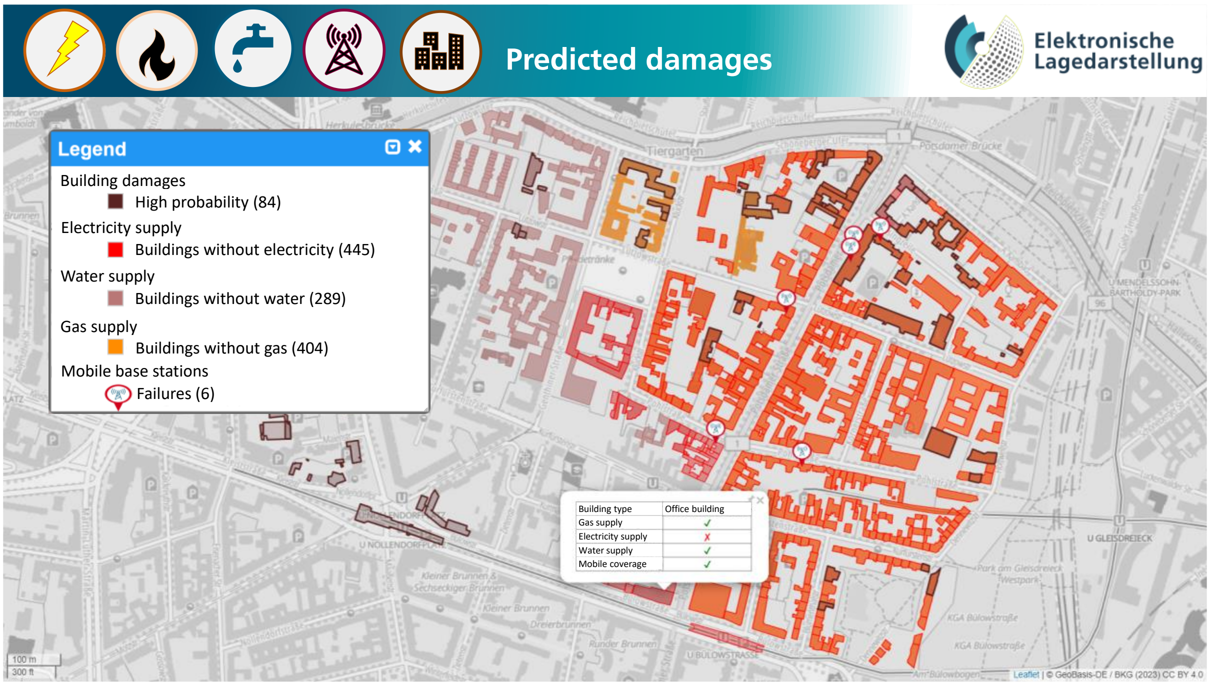

Figure 2. Example visualization in ELD of a predicted multi-layered failure cascade of critical infrastructures (Map data: CC BY 4.0: © GeoBasis-DE / BKG (2023) CC BY 4.0[2])

MobiKat®

Figure 3 shows a simulated crisis scenario in MobiKat® (Fraunhofer IVI MobiKat®, n.d.). It displays the same situation as in figure 2 but focusing on the first responders and respective incidents with subsequent tasks which are partly connected to the infrastructure failures displayed in figure 2. Different types of tactical units from police, fire department and emergency response are assigned to separate missions according to the needs to resolve realistic incidents (see tree view on the left in figure 3). The location and status of each unit is updated dynamically and displayed with its tactical sign on a map in MobiKat® (see map part in figure 3). Additionally, different kinds of statistics characterizing the situation and the availability of resources are being integrated into MobiKat® (see right hand side of figure 3). This provides a good overview of the considered situation and the distribution of resources tailored for users from authorities and organizations responsible for public safety.

MobiKat® is chosen here, because it is a well-established, modular system for the operational command and administration of the corresponding necessary resources. Its user groups are the command staff and relief forces from fire and rescue services, as well as disaster managers and police forces. The system offers various hardware applications for all command levels. The main features are:

- Display of geoinformation about the operation site – e. g., traffic network, aerial images, buildings, land use, information about the terrain
- Visualization of operation-specific information – e. g., flooding zones, tapping points for extinguishing water, critical infrastructures, current water levels, weather, construction sites
- Overview of available staff and resources
- Overview of damages, affected persons and measures
- Documentation of the operation
- Algorithms for the optimization of decision support
- Synchronization of all situational information
- Offline capability and local data storage

In addition to the distributed operational command feature working across levels and organizations with an integrated map, MobiKat® functionalities also include the administration of tasks and appointments, overviews adapted to the current situation as well as analysis and documentation options.

[2] https://creativecommons.org/licenses/by/4.0/

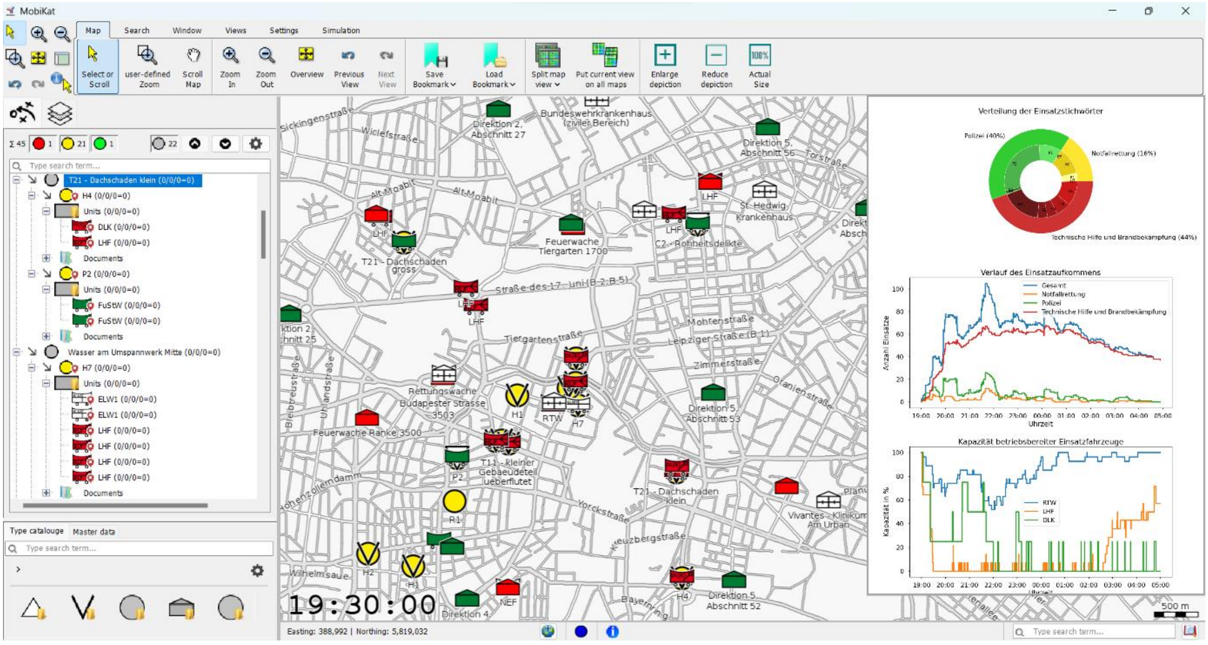

Figure 3. Example visualization of the activity of first responders in MobiKat® (Fraunhofer IVI MobiKat®, n.d.) during a predicted multi-layered failure cascade of critical infrastructures. (Map data: © 2022 OpenStreetMap contributors[3], © GeoBasis-DE / BKG 2019 (data changed))

Summarizing, the visualization and analysis of the aggregated and filtered data of the digital twin in MobiKat® is especially beneficial for users at authorities and organizations responsible for public safety.

DigLT

The *Digitaler Lagetisch* (DigLT, engl. *Digital Map Table*) is a versatile software system designed for collaborative situation visualization and analysis. It allows multiple users to work simultaneously on the same situation using personal computers, digital tables, or other visualization devices (van de Camp et al., 2021; Hoppe et al., 2020). The software is modular and customizable, making it suitable for various applications ranging from education to mission planning, execution, and review. It can integrate diverse data sources and geodata to provide relevant information for each use case, enabling users to make informed decisions.

In addition, the DigLT offers VR capabilities, allowing users to immerse themselves in the situation and experience it in 3D (Strentzsch et al., 2017; Hoppe et al., 2018). Figure 4 shows a screenshot of the VR environment of the DigLT with relief units depicted with tactical symbols. This feature enhances situational awareness and provides a more realistic and immersive visualization of the environment, which is especially useful for training and preparation for future missions. The symbols and icons displayed can be adapted to the needs of the respective user groups (e.g., emergency services, military), which enables a smooth transition from other situation reports.

In DigLT, the concept of individual visual layers allows for easy adjustment and filtering of map information, with the ability to stack and blend the layers for a comprehensive view. The software adheres to open standards, ensuring seamless access to various data sources. For instance, it offers extensive support for OGC and NATO standards, facilitating easy integration of geographical data.

Currently, the digital map table does not have an interface to the *OGC SensorThings API*. However, it is planned to implement this interface in the future. Once implemented, the interface will allow for the integration of the co-simulation results filtered according to the user's needs. For each simulator, this integration will involve creating a new layer on the map that displays all *Things* as corresponding icons or geometries based on the respective

Locations and time stamps. *Datastreams* and *Observations* will be made available as properties associated with each *Thing*. Thus, the DigLT's timeline tool gives the user access to the time-based progress of observed properties, e.g., water pressure or telecommunication network availability at selected sites and the cascading impact any status change has on other infrastructure. As a proof of concept, an interface between the operational

[3] https://www.openstreetmap.org/copyright

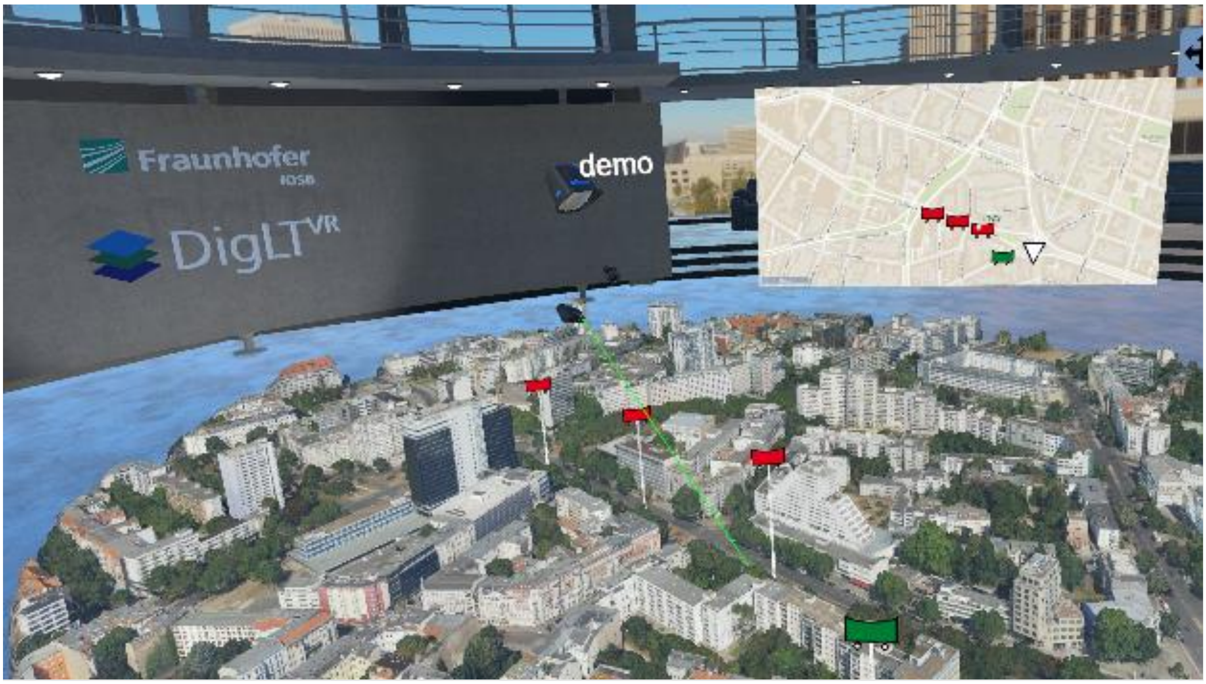

Figure 4. Example visualization of relief units in the virtual reality (VR) view of the digital map table (DigLT). A user is inspecting the current positions of emergency vehicles in the city center of Berlin. (Textures: © 2024 IBCAO, Landsat/Copernicus, Google; Map data: © 2024 GeoBasis-DE / BKG, OpenStreetMap[4])

dynamics simulation module and the DigLT has been established enabling spatial and temporal visualization of incoming emergencies and available relief units both in 2D and VR (see figure 4).

DISCUSSION

A comparison of the three tools for the visualization of simulation and sensor data, ELD, MobiKat®, and DigLT, reveals distinct functionalities that cater to different user groups and operational requirements. Each system offers a range of different functions, aggregates the data in a different way and therefore provides a different form of visualization of a (critical) situation.

On the one hand, the DigLT stands out with its VR capabilities, allowing users to immerse themselves in the situation. The advanced level of this features enables realistic scenarios and enhances situational awareness, both for individuals and in cooperative mode. On the other hand, these VR capabilities require more sophisticated visualization devices and VR equipment. The tool is therefore less suitable for widespread use in critical situations than for mission preparation and training.

The ELD provides decision-makers at all levels of government with a holistic view of the situation. The lack of real-time map updates makes it difficult to visualize dynamic situations and shifts the focus to a more granular view. In addition, the web-based platform offers functions to support staff work and crisis management in terms of communication, information and data exchange.

MobiKat® supports distributed operational use on all command levels and across organizations in desktop, web-based and mobile applications. Compared to ELD and DigLT, it has a more operative and tactical orientated interface aimed at authorities and organization for public safety. At such organizations it is used extensively in daily business as well as crisis situations.

Data integration and usable data sources are robust across all platforms. ELD, MobiKat® and DigLT support open standards, facilitating access to various external data sources. MobiKat®'s modular system allows for a comprehensive overview of public safety-related data. However, the DigLT currently lacks an interface to the OGC SensorThings API, limiting its ability to integrate FROST's sensor data. By addressing this gap in future updates, the DigLT will soon be able to adapt to the presented data processing and visualization pipeline.

In terms of data filtering and preparation for visualization, ELD, MobiKat® and DigLT use a layer-based approach that allows the user to tailor the data displayed. MobiKat® provides an overview of damage, resource and incident-

[4] https://www.openstreetmap.org/copyright

specific data, emphasizing the focus on immediate emergency management.

Recommended user groups for each tool align with these differences. The ELD is well suited for authorities and decision makers at all levels of crisis management who need a comprehensive overview of the situation with spatial data integration. MobiKat® is tailored for executives, emergency responders and disaster managers who need operational command and control and real-time updates. Finally, DigLT is recommended for users who have to deal intensively with the situation, such as emergency services, in order to carry out in-depth analyses and training.

When connected to the digital twin representation through the standardized interface, these tools offer complementary perspectives on the available data gathered in a critical situation and allow for efficient and possibly collaborative work flows in crisis management.

OUTLOOK

Quick action is often required to successfully respond to a critical situation. However, the ever-increasing amount of data available makes it difficult to act quickly in such situations. Data must be aggregated and prepared. A one-size-fits-all approach is not possible as different groups with different needs, such as decision makers, authorities, or infrastructure operators, are involved in the situation. User-tailored aggregation and visualization is therefore crucial for efficient crisis management, and different user groups may require different views of the situation.

The presented visualization approaches access a co-simulation framework (Martini et al., 2024) using the *OGC SensorThings API* standard. This allows for easy integration, also of other data sources, without the need to implement specific interfaces. Other visualization tools addressing further user groups can be easily added.

All presented approaches meet the objective of providing a visualization appropriate to the targeted user group. However, more work is needed to achieve seamless integration of the co-simulation framework and user-tailored visualization. Future work will therefore focus on two main areas: The further development of the tools already in use and the extension of the range of tools.

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