PANTHEON

Community-Based Smart City Digital Twin Platform

for Optimised DRM operations and Enhanced Community

Disaster Resilience

D8.1

REPORT OF PILOTS' OPERATION SCENARIOS

The project has received funding from the European Union's Horizon Europe programme under Grant Agreement N°101074008.

DOCUMENT INFO

Deliverable Number	D8.1
Work Package Number and Title	WP8 - Training & Pilots Set up-Execution-Evaluation
Lead Beneficiary	JOAFG
Due date of deliverable	29/02/2024 (M14)
Deliverable type[1]	R
Dissemination level[2]	PU
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Version - Status	2.0

[1] **Please indicate the type of the deliverable using one of the following codes**:
R = Document, report
DEM = Demonstrator, pilot, prototype, plan designs
DEC = Websites, patents filing, press & media actions, videos
DATA = data sets, microdata
DMP = Data Management Plan
ETHICS: Deliverables related to ethics issues.
OTHER: Software, technical diagram, algorithms, models, etc.

[2] **Please indicate the dissemination level using one of the following codes**:
PU = Public
SEN = Sensitive

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TASK ABSTRACT

The operation scenarios are the base reference for the development of the PANTHEON system. It defines both the conditions of use (dimensioning scenarios, rules of engagement, etc.) and the system specifications as defined by the community end-users. The task will issue a first approach at M14 to enable a quick start of the development phase. It will elaborate a second version of the report after the first training and exercises in Athens (version 1), based on the assessment and recommendations from the end-users.

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REVIEW HISTORY

Version	Date	Modifications	Editor(s)
1.0	24.01.2024	First draft	Benjamin Schuster (JOAFG), Sarah Kainz (JOAFG)
1.1	19.02.2024	First internal review	Ilona Grabmaier (JOAFG), Benjamin Schuster (JOAFG), Sarah Kainz (JOAFG)
1.2	26.02.2024	Internal review - SIMAVI	Ana-Maria Dumitrescu, Otilia Bularca (SIMAVI)
1.3	28.02.2024	Internal review – THL	Mike Karamousadakis (THL)
2.0	29.02.2024	Final touches and new format	Benjamin Schuster (JOAFG), Sarah Kainz (JOAFG

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
AI	Artificial Intelligence
API	Application Programming Interface
CONOPS	Concepts of Operations
C2	Command and Control Link
DRR	Disaster Risk Reduction
DRS	Disaster Response Systems
DT	Digital Twin
E	East
EO/IR	Electro-Optical/Infra-Red
GCS	Ground Control Station
GGCS	Generic Ground Control Station
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HALE	High Altitude, Long Endurance
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
LiDAR	Light Detection and Ranging
LTE CAT	Long Term Evolution Category
MALE	Medium Altitude, Long Endurance
NB-IoT	NarrowBand-IoT
N	North
N/A	Not Applicable
NE	Northeast
NW	Northwest
PSSUQ	Post-Study System Usability Questionnaire
SCDT	Smart City Digital Twin
Smart DRS	Smart Disaster Response Systems
SSH	Social Sciences and Humanities
SSL/TLS	Secure Sockets Layer / Transport Layer Security

SW	Southwest
TRL	Technology Readiness Level
UAS	Unmanned Air System
UAV	Unmanned Aerial Vehicle
UCS	Use Case Scenario
UI	User Interface
UNDRR	United Nations Office for Disaster Risk Reduction
VTOL	Vertical Take Off or Landing
6LoWPAN	IPv6 over Low-Power Wireless Personal Area Networks

If not otherwise indicated, this deliverable adheres to the SENDAI framework Disaster Risk Reduction Terminology (Sendai Framework Terminology on Disaster Risk Reduction | UNDRR, 2023).

EXECUTIVE SUMMARY

This Deliverable describes the efforts made so far in planning for the pilots of the PANTHEON system, while tailoring the systems' capabilities to the testing performed based on end-users' needs. Major groundwork was already laid in other Work Packages, especially WP2 and WP3. (see Chapter 3) This deliverable describes the hand-over from other work pages to WP8, the reasoning behind prioritisation of certain development directions and the future side-by-side development of the PANTHEON system with the pilots. Deliverable 8.2, with the same title as this one, will present the conclusion of this development effort, making D8.1 an interim report to be concluded in D8.2.

The pilots showcase two application areas for the PANTHEON system - its use as a training and exercise tool, and its use as a planning and early warning tool (see Chapter 4), in four different hazard scenarios in two pilot regions. A wildfire and earthquake scenario set in Athens, and a heatwave and man-made disaster scenario with its cascading effects in Vienna. (see Chapter 5) The pilot scenarios will make use of all the relevant technologies involved in the PANTHEON project, including simulation technology, visualization technology, drones, Internet of Things (IoT), and sensor data (see Chapter 6). The outcomes of the pilots will be evaluated, work which will mostly be done in T8.5. Evaluation of the pilots may include quantitative as well as qualitative methods (see Chapter 7). The execution of the pilots is planned for mid to late 2025 (see Chapter 8).

1 INTRODUCTION

The pilot scenario development is derived from the work done in co-creation workshops and stakeholder analysis, to make sure that the system can be tailored to the needs of users active in disaster resilience building and disaster response and incorporates the concept of vulnerable groups in the foundation of the system architecture. A user advisory board has been established to collect feedback along the pilot design process and create a system relevant to the needs of its intended users.

For the pilot scenarios it is planned to demonstrate use cases covering all the technologies being developed in the PANTHEON project. Though not all the capabilities of the system might be of interest for every end-user target group, the whole range of simulation capabilities of the system will be presented to all users of the system during the piloting phase. In this way, meaningful feedback regarding applicability of the individual components can be gauged considering each user's field of work.

Use cases for the platform were created in WP3, constituting the basis of the usage scenarios to be piloted. To be able to present a broad picture of the possible application fields of a Digital Twin (DT), the requests and suggestions of the Disaster Risk Reduction (DRR) specialists participating in the project were emphasized, but naturally those were not the only ones considered to be incorporated during the pilot scenario creation. During the T3.6 workshops an overlap needed to be found between technical system capabilities and usable simulation possibilities. The simulation systems' respective potential application fields at the project's end-user organisations is now being gauged and will be the foundation of further development efforts. Pilots will have to consider those overlaps with respect to potential participants during the pilot tests. More precisely, up until this point, the needs of stakeholders in DRR were evaluated and a common basis for the development direction of the system's capabilities was established. Results of the ongoing discussions in multiple working groups across several work packages were incorporated in the final scenarios, factoring in technological capabilities on the one hand, as well as probability and effect of specific disasters on the communities in the two pilot regions on the other. The pilot scenarios consider the technologies that are to be showcased, the selected relevant hazards, and the prospective end-users of the PANTHEON system (see Figure 1). The resulting recommendations and an overview of the whole scenario development will be documented in Deliverable D8.2.

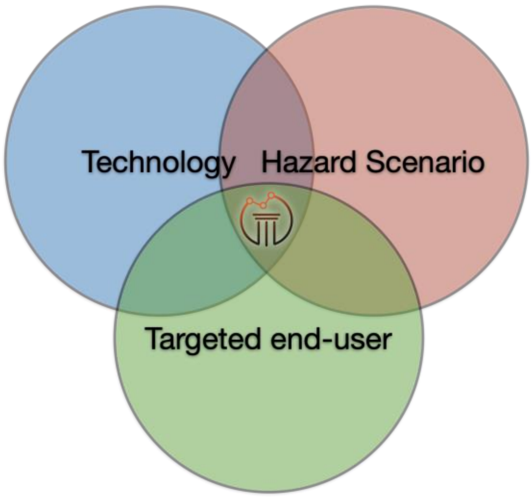

Figure 1 Considered development input from previous workshops

At the moment of this deliverable's submission, a consensus within the group of partners of WP3 has been reached to select two natural disasters for Athens and one natural as well as one man-made disaster in Vienna. They are:

- wildfire and earthquake in Athens,
- heatwave and man-made disaster modelled after a real-life exercise in Vienna.

For the pilots, the system's capabilities will be built out with a focus on planning and training. WP3, and especially T3.6, was used as the main development effort to establish the technological capabilities of the system to be tailored for stakeholder needs.

Evaluation of the PANTHEON system after the pilots' deployment are expected to ascertain the usefulness of existing system components and collect feedback regarding missing components that could ensure effective deployment across pilots and future usage.

2 STATE OF THE ART OF TYPICAL APPROACHES FOR PILOTING TECHNOLOGY IN THE CONTEXT OF BUILDING A DISASTER RESILIENT SOCIETY

The concept of “resilience” has followed humans from the dawn of time. Nowadays, more and more efforts are needed to build community resilience in the face of natural and human-made hazards and disasters.

There are several definitions for the concept of “resilience”. The United Nations Office for Disaster Risk Reduction (UNDRR) for instance defines it as “The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.” (UNDRR, 2017). A thorough grasp of resilience, as defined by institutions such as the UNDRR, is necessary to acknowledge the critical role that technologies play in creating resilient communities via efficient disaster management techniques. Building stronger and more adaptable communities requires a strong link between disaster management and community resilience, and these two concepts cannot be improved without technologies.

The goal of the PANTHEON project is to design a Smart City Digital Twin for Athens and Vienna. The "Smart City" concept refers to a category of ideas and conceptions for urban environments that use contemporary technology to make cities more efficient, and consequently more climate-friendly and livable (Smart City - Definition und Anwendungsbeispiele | EnBW, n.d.). As a result of the growing vulnerability of urban ecosystems, including Smart Cities and the rising awareness of disaster risks, making Smart Cities disaster resilient is not only a timely need, but should be a natural extension of accelerated urban development. Over the last decades, there has been a significant improvement in cities adopting the Smart City vision and utilising technology solutions for effectively managing hazards and enhancing resilience (Samarakkody et al., 2023). According to MacAskill and Guthrie (2014), disaster resilience involves additional work to what is currently done in disaster risk management, and should be the guiding principle for urban development, emergency/crisis management, and disaster risk management. Rauniyar et al. (2016) contend that, although technologies cannot stop disasters from taking place, they can be very useful for disaster preparedness, especially including prediction, early warning, and post-disaster rescue operations.

There are several technologies that are being researched and used for disaster resilience and it is necessary to select and test what is best suited for “Smart City” resilience. Therefore, there is a need to explore the potential of proposed new technologies to improve disaster resilience in Smart Cities. To achieve this, it is necessary to identify technologies by their impact on creating, enhancing, and maintaining disaster resilience in Smart Cities. Consequently, there is a clear need for interdisciplinary research that will help integrate technology with the social sciences (Samarakkody et al., 2023).

Stratigea et.al. (2015) list the tools and technologies commonly applied in Smart Cities, divided into three categories, as follows:

- Technologies and tools for citywide geodata collection and management including cloud computing, sensor networks, location-based services, geo-visualization, Geographic Information Systems (GIS), mapping, the IoT, unmanned aerial vehicles (UAVs), Smart Disaster Response Systems (Smart DRS), Early warning systems, data warehouses, etc.,

- Technologies and tools for public participation (crowdsourcing platforms, web-based participatory tools, Social Media, Living Labs, etc.),
- Sectoral applications (for example energy, transport, environment, etc.).

According to Guseva et al. (2021), the main restriction that hinders the full-scale deployment of Smart City infrastructure is that the expensive Smart City solutions are still at the introductory and approbation stages and not yet ready for scaling. Therefore, the maturity of technology is important when prioritizing the resources within Smart City infrastructure, especially considering limited ones, which are allocated towards DRR. As a reference measure one of the most widely used international assessment tools is the Technology Readiness Level (TRL) scale. As Engel et al. (2012) noted, the scale depicts nine evolutionary stages that abstract how far a technology is from being proven successful in operations environment and ready for full commercial deployment.

Using the most suitable and feasible tools and technologies is a measure of smartness in a Smart City. There are four key factors according to which these technologies can be assessed: impact on society, the adoption speed by Smart Cities, the maturity of the technology, and the capabilities offered to the community (Samarakkody et al., 2023).

The state of technologies to be piloted is dynamic and subject to change as new breakthroughs, discoveries and advancements occur. When piloting technology in the context of building a disaster-resilient society, it is essential to adopt a comprehensive and integrated approach. That typical approach usually contains considerations such as: risk assessment and identification, early warning systems, community infrastructure, and blockchain for resilient infrastructure. Early warning systems are intended to guard against a range of threats, including those present in an urban disaster scenario, including risks to human health, industrial, biological, and complex socio-political events. During emergencies and natural disasters, it has been demonstrated that sending alerts and warning messages to vulnerable communities greatly reduces the amount of material and human losses (Carsell et al., 2004; Fakhruddin et al., 2020). As Riaz et al. (2023) note, many studies have been conducted on early warning systems, which use real-time data to generate warnings for natural hazards. McIsaac, et al. (2019) for instance state that disaster resilience can be revolutionized by blockchain technology, particularly in managing refugee aid and funding. Blockchain is a distributed ledger technology used for safe, auditable, and verifiable information (value) storage and transmission. Another aspect of piloting technologies are drones and unmanned aerial vehicles, because of their ability to expand cellular coverage and bandwidth for disaster relief efforts and other purposes. According to Ali et al. (2023) drones are frequently seen as an expedient solution during disaster rescue missions when regular wireless networks are disrupted. Likewise, Qadir, et al. (2021) state that even in remote areas, UAV-derived aerial imagery of disaster-affected areas helps expedite evacuation and ensures that supplies are transported safely.

One more area of piloting technologies are geospatial technologies. Currently, location-based data can be obtained with one or more of the many outdoor and/or indoor positioning determination technologies, which are classified as terminal/user-centric, network-centric, and hybrid solutions. The first global location system in use is the satellite-based Global Positioning System (GPS). Regardless of the underlying delivery technology used to convey its information, location-based services are broadly defined as any service that provides relevant information about the current location of an active mobile handset at a given window of time (Aloudat and Michael, 2011). A detailed account of the technologies to be used and piloted in the PANTHEON system can be found in Chapter 6.

The typical approach of piloting technologies - in the context of creating disaster resilient societies - includes data analysis, artificial intelligence (AI), and remote sensing technologies, which permit quick recovery and lessen the domino effects of the destruction of vital infrastructures. The technological aspects of societal change that propel the societal response to risks and disasters are AI applications, such as tracking and mapping, remote sensing techniques, geospatial analyses, telecom and network services, smart city urban planning, accident and hot spot analyses, environmental impact analyses, and transportation planning (Abid et al., 2021).

The establishment of a robust monitoring and evaluation framework enables the assessment of effectiveness of technology interventions and the regular review and update of technology solutions, based on lessons learned from any past incidents. Improvements in technology are frequently made without any kind of measurement, either prior to or following the change. However, there is less confidence in the result of an innovation or the effectiveness if changes are not validated. Conducting a pilot project before the start of a pivotal study or the launch of a product can significantly increase the likelihood of success and potentially prevent the initiation of failed pivotal studies. Pilot studies provide a valuable opportunity to evaluate the practicality and viability of conducting large-scale, comprehensive studies. They serve as a critical step in assessing the feasibility of conducting an extensive and expensive full-scale study, which is often considered an important prerequisite.

To be effective, pilot studies must be carefully planned, include clear feasibility studies and well-defined analytical plans. According to Lancaster et al (2004), conducting pilot testing involves several key steps:

- Defining the purpose of the study,
- Selection of key data for analysis depending on the objectives of the study,
- Preparing researchers for pilot testing,
- Conducting pilot testing,
- Evaluation of results,
- Using the results of a pilot test to make changes to a larger test.

Conducting and evaluating pilot testing will allow the following steps to be taken:

- Identifying any potential risks associated with the study and taking measures to reduce them,
- Analysis of the results of the pilot project and its feasibility study,
- Development of data collection and analysis methods for the larger study, including any changes indicated during pilot testing of the project.

In conclusion, the quest for building disaster-resilient communities demands a holistic and integrated approach, and technology plays an essential role in achieving this goal. The intersection of technology and disaster resilience is especially clear in the context of Smart Cities, where progress has been made in adopting innovative solutions for effective hazard management. Only reforming the environment of technology, coupled with a commitment to continuous improvement and validation, will contribute to the creation and maintenance of disaster-resilient societies in the face of ever-changing hazards and challenges.

Another important factor in ensuring the success of an innovation or technology is to consult with the community and end-users concerning the needs and gaps that this new solution should cover. This inclusion should – as was the case with PANTHEON - ideally happen as part of a participatory design process, which should accompany the development of the design and specifications for the new technology.

3 PANTHEON'S PARTICIPATORY DESIGN PROCESS

In PANTHEON, the participatory design process (T3.2; see Bittner et al., 2023) was based on findings and analysis done in WP2, specifically in T2.1, T2.3, T2.5 and T2.6. From T2.1 (see Tsaloukidis et al., 2023), the design process utilised the analysis on the regulatory frameworks for each pilot site (Athens/Greece and Vienna/Austria). From T2.2 (see Triantafyllou & Apostolopoulou, 2024), the design process utilised the analysis of risks and relevant hazards associated with the pilot areas and the impact assessment consideration. From T2.3 (see Kainz et al., 2024), the design process captured the community vulnerability and capacity assessment in the pilot regions, including the analysis on the role of vulnerable groups in the decision-making during disasters. From T2.5 (see Bittner et al., 2024), the design process acquired the methodological framework and the design criteria to be followed, based on the existing approaches for participatory governance. Finally, from T2.6 (see Kostolny & Dikosova, 2023) the design process gathered design considerations for building disaster-resilient communities.

All the previous inputs created a solid framework for the participatory design process to be materialised in T3.2. The process started with a stakeholder and end-user analysis, continued with the definition of key terms to be used during the participatory activities, and was finalised with a specific method that was followed for designing the participatory activities.

For the stakeholder and end-user analysis, an extensive list of stakeholders was created for each pilot region, that was further divided into three main groups, based on their level of responsibility. These were:

- Administrations – high level and political decisions,
- First responders – operative and on-site responsibilities,
- Communities – with no responsibility a priori.

To materialise the participatory design process, a literature review was implemented with several scientific papers and approaches being identified and researched. After conducting an analysis on these, the social sciences and humanities (SSH) experts involved in the PANTHEON project carefully crafted a suite of methods that could allow community participation and stakeholder/end-user involvement from an early point in the project cycle. For this purpose, the methods of group discussion in the form of semi-structured interviews, brainstorming/brainwriting, timelines, the Walt-Disney Method and the use of the interactive online whiteboard “Concept board” were applied in several workshops with stakeholders and end-users from the focus areas of PANTHEON.

3.1 CRITERIA FOR THE SELECTION OF SCENARIOS

To identify specific criteria for selecting the disaster and usage scenarios for PANTHEON, the partners relied on the previous work done in T2.1, T2.2, T2.4 and T3.2, as detailed below:

- Within T2.1, criteria were created and applied regarding a *suitable regulatory and operational framework*. This was based on the fundamental premise that PANTHEON could not be operationalised and applied for a disaster in a pilot region that lacks the necessary regulatory and operational framework for that specific disaster. Based on this analysis, a range of disasters was considered, since existing regulatory and operational frameworks from the local authorities for these disasters were needed to enable the analysis, design, development integration and deployment of the PANTHEON system.

- T2.2 defined the criterion that was created and applied in PANTHEON was based on *high-risk hazards*. The analysis done in T2.2 enabled the creation of semi-quantitative tables with specific hazards that have high probability and/or high impact on the under-study regions. The role of these tables was significant in decision making for the disaster and usage scenarios. T2.2 also considered *community-based hazards*. This enabled the creation of concrete answers related to the question "which disasters does the community of the under-study region think most important". These answers offered the community perspective towards arriving at specific disaster scenarios in PANTHEON.
- As part of T2.4 (see Chrobocinski et al., 2024), the criterion that was created and applied in PANTHEON was *technical feasibility*. The literature review done in T2.4 provided the necessary technical feedback that was necessary to conclude on disaster and usage scenarios that are not only important from the literature review and the community perspective, but also technically feasible with PANTHEON's existing technologies.
- Finally, within T3.2, the criterion that was created and applied in PANTHEON was *the selection of disasters based on potential applications from stakeholders*.

Following the analysis of the results from the implemented participatory design process, specific criteria were concluded as to which potential applications were feasible for PANTHEON's available technologies, with a special focus on the Smart City Digital Twin (SCDT). The potential applications that were eventually gathered were described in D3.2 and can be seen in Table 1.

Table 1 Potential applications of the PANTHEON system as described in D3.2

Disaster Phase	Potential Application	Description
Before a disaster	Planning and early warning according to simulations (A)	Using models and simulations based on big amounts of valid data to calculate possible evolutions of scenarios. Especially for scenarios for which little experience exists in the region, this could enable the development of emergency plans. Certain structures (e.g., staging areas) could be pre-defined for specific locations. Also, large-scale evacuations may be planned according to simulations if they cannot be trained in reality. The system might be used to give a prognosis of best-case and worst-case consequences for different scenarios that can be adapted, or it may serve as an early warning system, constantly monitoring the modelled area.
	Training and exercises (B)	Training realistic scenarios is very important for first responders and disaster response, but large-scale exercises are very complex to organize and expensive. Table-top exercises, on the other hand, tend to require high levels of phantasy. A SCDT could fill this gap and even facilitate regular cross-organisational trainings increasing the mutual understanding of other organisation's needs. Models can simulate the evolution of situations and shed light on approaches and priorities that have not been thought of yet. Also, the system may be used to map and develop different scenarios for large-scale exercises.
During a disaster	Situational picture (C)	During the first phase of an emergency (chaos phase) the system might be helpful to assess the situation on site and help in the early estimation

		of potential damage. It may also allow to quickly identify surrounding vulnerabilities (critical infrastructure, schools etc.), classify the incident and deliver crucial data for the orientation of emergency services.
	Cross-organisational communication (D)	Different organisations have different information available (especially during the early phase of a disaster). If all involved organisations have real-time access to the system, it may serve to share information across organisational boundaries and enhance cross-organisational communication and coordination.
After a disaster	Documentation and evaluation (E)	Operations may be documented within a SCDT. In other words, a digital twin of operations is designed within the SCDT. This could either happen according to the input during the disaster response and its storage or through the replication afterwards. This application could facilitate better understanding and transparency of actions taken and support legal security of operations, while providing an ideal foundation for evaluation of operational strategy.

Based on the previous criteria and after an iterative process in workshops and discussions between developers and end-users, the technical partners along with the pilot representatives arrived at the definition of the following disasters and potential applications (two for Athens and two for Vienna) to be piloted:

For Athens, the first disaster to be examined is a wildfire with potential application B, meaning PANTHEON should facilitate training and exercises towards a wildfire happening in the metropolitan area of Athens. The second disaster scenario is an earthquake with potential application A, meaning PANTHEON should provide planning and early warning according to simulations towards an earthquake happening in the metropolitan area of Athens. For Vienna, the first disaster to be examined is a heatwave with potential application A, meaning PANTHEON should provide planning and early warning according to simulations towards a heatwave happening in the metropolitan area of Vienna. The second disaster that is concluded is a wildfire happening after a cyber-terrorism attack with potential application B, meaning PANTHEON should facilitate training and exercises towards a wildfire caused by a cyber-terrorism attack, happening in the metropolitan area of Vienna. The next sections provide more details on the defined potential applications and disaster scenarios showcased in the PANTHEON pilots.

4 SYSTEM COMPONENTS TO BE PILOTED

Establishing novel digital training and planning tools in general needs to undergo an evolution of slow growth from a supplemental information system to a tailor-made solution capable of extending existing training and prediction capabilities and finally maturing to a solution capable of replacing parts of established exercises in the time-proven training regimes and predictive planning and early warning tools of organisations active in DRR. To enable this process, the aim of the pilots will be to simulate scenarios in a way that is closely modelled after typical analogue exercises and show the added value of the platform's simulations and projection capabilities as a planning tool. All this is to be accomplished while building upon the project's first responder partner organisations' experience in ensuring their relief forces' operational capabilities.

The components to be piloted will be derived from technologies that are being developed in PANTHEON and showcased from different perspectives regarding training and planning. The pilot's operational scenarios are created in a way that makes sure all major technological components will be showcased individually through added emphases in each of the four pilots regarding different capabilities relevant to the scenario. The sequence of different scenarios will at the same time steer the development effort of the platform's underlying building blocks so nascent components will still be presented even in early development while ascertaining the pilots' smooth execution.

4.1 TRAINING AND EXERCISE TOOL

Practical exercises without patient contact are an essential part of emergency services‘ training curricula. At Johanniter rescue services in Austria (JUHÖ) (see https://www.johanniter.at/), about 50 per cent of the legally required training is facilitated through practical exercises without patient contact.

Practical exercises constitute an enormous burden regarding both human and monetary resources. A typical field exercise usually takes at least half a year to organise, requiring a workforce of six people or more. The exercises themselves constitute the gold standard regarding realism and quality of training but usually consist of a single scenario iteration. The combination of the high resource demand and limited repeatability very clearly show a need for simulation systems that can help supplement the existing training regime.

The PANTHEON system's usage as a training platform stems from its ability to react to adjusted parameters of a simulation, thus creating an exercise-like feedback loop consisting of:

- Realistic scenarios presented to trainees (Defining the scenario corner stones)
- Collecting the responses and output from trainees regarding the scenario as a new system input (Relativizing the scenario)
- Redefining the scenario by incorporating the trainees' actions, thus presenting them with tangible results of their actions (Redefining the original scenario and starting over)

In educational concepts, repeatability is one of the most effective means to create confidence in emergency responders during training situations that can still have an effect during real-life deployments. Theoretical knowledge needs to be supplemented by practical application of said knowledge. This usually takes place by either very abstract table top exercises or extremely realistic but exceedingly elaborate thus infrequent practical exercises. A sophisticated simulation tool like the PANTHEON system fits right into the void between real life exercises and pure tabletop trainings.

An often-voiced request of educators in first responder training facilities is to be able to train for a more diverse set of disaster scenarios as now, the resource limitations imposed by real life exercises mean that only a small selection of the most typical and most likely disasters are actually trained for in any practical fashion. This is often summarised as a wish to be able to “train the hard to train for scenarios”. Thus, we aspire to refocus education from the pragmatic perspective of a resource constraint caused scenario selection to a broader spectrum of much more easily implementable simulation trainings.

4.2 PLANNING AND EARLY WARNING TOOL

The primary focus of PANTHEON’s output is to provide actionable insights for optimal planning and resource allocation during disasters. The tool’s output aims at aiding the effective response to mitigate the impact of disasters on critical infrastructure and nearby communities by serving as a planning asset for first responders, offering insights that go beyond static planning, such as simulating concepts for strategic allocation of resources in both space (e.g. best routes to mitigate distance to disaster) and time (e.g. fastest response positions that maximize impact mitigation). The tool's dynamic nature, scenario simulations, and scenario-based decision support, will ideally allow it to seamlessly integrate data from various sources, including seismic data, satellite imagery, drone footage, and weather conditions, forming a comprehensive overview of the dynamic disaster landscape in terms of area affected and likelihood of disaster maximization. A User Interface (UI)-friendly dynamic representation will allow system users to incorporate algorithms to predict consequences and quantify the impact on different areas. Through this, first responders will use it to gain valuable insights that go beyond traditional approaches. By optimizing the spatial and temporal deployment of resources, the tool will ensure a swift and effective response to mitigate the impact.

Specifically, the systems’ development target for the pilots is a maturity level that enables simulation of risk chains and cascading effects, which depict interconnected infrastructures, urban areas, systems, and their dependencies. In the context of a specific disaster, PANTHEON will analyse the interplay between critical infrastructures and how they become affected by each disaster. The tool’s risk chains will provide valuable insights beyond traditional route planning, offering not only the shortest route to the heart of a disaster (if we consider PANTHEON’s capability to analyse the effect of the disaster onto the road network) and also the best impact-to-reachability route for first responders (considering which positions to prioritize first given specific resources, the amount of impact per area or infrastructure and the time needed to reach it).

Moreover, PANTHEON's risk analytics will contribute to resource planning that considers not only physical proximity but also the potential domino effect of infrastructural failures. For example, in a scenario where an earthquake disrupts a water supply network, the tool identifies not just the closest water source, but also the one whose restoration would have the most substantial positive impact on affected communities. This dynamic approach to route planning ensures that resources are re-directed strategically, addressing the most critical dependencies, and mitigating the broader consequences of the disaster.

This utility ensures that first responders not only reach the heart of a disaster quickly but also make decisions that have a cascading positive effect on the entire network of critical infrastructures. The tool can thus become a strategic ally for first responders, offering a nuanced understanding of the interdependencies that shape the impact of disasters, ultimately enhancing the effectiveness of resource allocation in complex emergency scenarios.

5 SCENARIOS AND CONDITIONS OF USE

Pilots for the PANTHEON system are derived from use-cases that have been developed during workshops in WP3. The aim of all the pilots will be to showcase the whole system with all its capabilities while enabling an emphasis of certain components focused on the specific pilot.

The first two pilots will take place in the Region of Attica and the metropolitan area of Athens. Here, two main scenarios are considered, based on which the PANTHEON tool will be deployed. The first scenario refers to a wildfire, while the second one addresses the occurrence of a strong earthquake.

The final two pilots will take place in Vienna. The third and fourth pilots of the PANTHEON project will focus on training of heatwaves respectively the simulation of a man-made disaster such as (cyber-)terrorism.

All scenarios are described extensively in the Deliverable D3.6 “Project use case specification and scenarios” (Karamousadakis et al., 2024).

5.1 ATHENS

5.1.1 WILDFIRE SCENARIO

The first scenario is related to the occurrence of a wildfire in the area around the NW (north western) suburbs of Athens. Specifically, during the afternoon hours of {the pilot date}, a forest fire is ignited in the proximity of the Fyli town, at the SW (southwestern) slopes of the Parnitha mountain. Although the fire does not burn densely forested areas, due to strong NE (north eastern) winds, it threatens nearby critical infrastructures.

The potentially severely affected infrastructures are transportation hubs, especially the highway and railway that lie at the SW of the fire, the nearby gas installations, and the large dumping ground of Athens which may create a toxic plume of smoke. In addition, the water and power supply networks can be damaged leading to supply disruptions and collapse.

The first indication of a wildfire is reported by witnesses to the 112-emergency call centre. The information is then dispatched by the National Coordination Centre of the General Secretariat for Civil Protection to all relevant stakeholders who engage in response operations. The main agency responsible for the management of wildfires in Greece is the Hellenic Fire Service, which undertakes fire-fighting operations. Moreover, the Hellenic Police takes curfew measures to facilitate the incoming flow of fire-fighting vehicles, while concurrently assisting in the evacuation of the affected population should the need arise. Finally, the National Centre for Emergency Assistance can be engaged for the medical evacuation of the injured or people who might develop respiratory issues due to the smoke.

Simulations can provide a valuable training ground for first responders. By simulating different disaster types, first responders can refine their resource allocation strategies. PANTHEON will pilot scenarios that showcase these capabilities.

Consider a wildfire scenario where the fire threatens transportation hubs and energy facilities but is also encroaching on a natural gas supply network with multiple chokepoints. The Fire Service, with resource usage insight and situational overview from the tool, can swiftly allocate resources like fire trucks to maximize the impact reduction from firefighting efforts and meet the needs of affected communities by using the tool’s output based on the current wildfire positioning, vulnerability of gas chokepoints and potential impact to specific populations per chokepoint. The ability to receive continuous updates and adapt resource allocation strategies in real-time is crucial for effective disaster management.

PANTHEON's risk chains will analyse the dependencies between the affected infrastructures, revealing the critical nodes that, if protected or addressed first, can minimize the overall impact on the interconnected network; for instance, by prioritizing the protection of a specific energy facility, a gas pipe or a small road junction that greatly affects multiple routes towards the disaster area. The tool guides first responders to allocate resources strategically, not just based on proximity but also on the potential cascading effects that could be mitigated by safeguarding that specific infrastructure.

5.1.2 EARTHQUAKE SCENARIO

The second scenario refers to the occurrence of a strong earthquake within the Region of Attica, a few km NW of Athens. The earthquake is caused by an active fault at the SW slopes of the Parnitha mountain. The coordinates of the epicentre are 38.08 N (north) and 23.60 E (east), the magnitude is 6.3 R and the focal depth of the earthquake is 9.5 km. The earthquake occurs at 03:00 a.m. on {the pilot date}.

The earthquake is strong and shallow; therefore, it leads to severe damage and generate unexpected secondary events of strong impact (cascading effects). Landslides are observed and lead to the blocking of the road that leads to the military base at the peak of the Parnitha mountain. Ground deformations are observed mainly in the western parts of the Region and lead to damage in the railway. Soil liquefaction is another cascading phenomenon as it can lead to ground failure and subsequently collapsing of buildings, affecting again the western parts. The reason why western Attica is more severely affected by these phenomena is the geology of the area, which comprises soft and saturated soil that behaves like a liquid when affected by the shake of the earthquake.

Several critical infrastructures are affected by the seismic event including the sector of energy, with natural gas stations and pipelines damaged, the transportation sector, with the railway being more severely affected, telecommunications disruption and power shortages throughout the city of Athens.

Reports regarding collapsed and heavily damaged buildings are received by the 112-emergency call centre, which then dispatches the relevant information to all engaged first responders' organisations. The Hellenic Fire Service is responsible for search and rescue operations. Due to the occurrence of the earthquake very early in the morning there is an increased probability for many casualties as well as of entrapments beneath the debris. The National Centre for Emergency Assistance is mobilised for triage and medical evacuation and treatment of injured citizens. The Hellenic Police assists in evacuation procedures and regulates the traffic.

In a common-cause disaster that simultaneously affects infrastructures in a wider area, such as an earthquake, the risk chains can guide resource allocation by factoring in the dependencies between disrupted transportation hubs, areas with maximum impact per capita and failure of telecom networks due to cable malfunction. Rather than merely focusing on the shortest route, the PANTHEON tool considers the broader impact of multiple disrupted services on various critical infrastructures. Given a specific area of effect, first responders can then prioritize the restoration of specific infrastructure nodes that have the most significant impact in terms of being the initiating factors that may cause multiple cascading effects (e.g. specific single-point-of-failure antennas or flammable infrastructures) on the overall connectivity and accessibility of affected areas. This nuanced approach ensures that resource deployment aligns with the interconnected nature of critical infrastructures, enhancing the overall efficiency of the response.

5.2 VIENNA

5.2.1 HEATWAVE SCENARIO

As a resource usage training model aimed at dispatchers and planners at operations centres, this scenario will showcase the PANTHEON platform's simulation capabilities with a focus on the creation of a realistic depiction of dwindling resources during a heatwave.

Heatwaves have already been and will increasingly be a danger in Vienna based on historical weather data and projections. Vienna has experienced a significant increase in the frequency of heatwaves with temperatures above 30 °C in recent decades. The Austrian central meteorological institute issues warnings for extreme weather events, including heat stress, which among many other problems causes exacerbations of health issues especially noticeable in the ageing population with cardiovascular conditions. This in turn causes spikes in ambulance calls. The summer of 2015 set a record with 42 heat days, and projections suggest an increase in summer days from 65 to 100 per year by 2071-2100 (City of Vienna, Water Management, n.d.).

In the heatwave pilot scenario, the effects of heatwaves on the population and medical infrastructure are explored, emphasizing increased morbidity and mortality. Vulnerable groups, such as the elderly, chronically ill, and socio-economically weaker individuals, face heightened risks. The cascading effects of heatwaves (including a higher number of ambulance operations as well as personnel absences due to holiday leave) strain resources, requiring long-term planning for first responder organizations. The pilot scenario in Vienna focuses on ambulance call-outs and changes in hospital occupancy, with a need for triage systems and resource management.

The two major topics to be trained here will be:

- reprioritisation of transports regarding waiting times of patient groups considering weather conditions in combination with age and medical conditions.
- Switching from regular operations to a triage system and stopping all non-essential operations

Stakeholders, including operations centres, equipment providers, and human resources, must prepare for heatwaves in advance. Plans for patient prioritization, equipment assessment, and communication during overlapping holiday seasons and heatwaves are crucial. The PANTHEON system is highlighted as a predictive tool for training and resource management in responding to different heatwave scenarios.

This pilot training exercise will mainly focus on a digital twin's ability to have multiple runs through variations of a scenario presenting not only a simulation but also dynamically showing the effect of the trainee's inputs.

5.2.2 MAN-MADE DISASTER MODELLED AFTER REAL-LIFE EXERCISE

The fourth and final pilot scenario for the PANTHEON system is focusing on a man-made disaster in Vienna. The scenario is to be based on a real-life exercise from the Horizon 2020 TREEADS project, with the goal of showcasing the system's ability to closely simulate disaster situations and supplement real-life exercises for first-responder organizations and DRR stakeholders.

The chosen reference exercise centres on wildfires and their prevention, with the PANTHEON narrative incorporating a man-made trigger - a cyber-attack on a power plant leading to a forest fire spreading towards Vienna's outskirts. The scenario aims to simulate cascading effects, involving various organizations such as firefighters, police, medical responders, and others, as the disaster progresses towards densely populated areas.

As the final pilot is going to be a staff exercise, the pilot will mainly be the PANTHEON system's capability test. It will showcase cascading effects regarding infrastructure damage and flow of people.

Attention is given to vulnerable groups in the affected area, and the system's ability to account for special measures, communication, and logistics is observed. By using a real-life exercise as a reference, the PANTHEON project aims to closely mimic a disaster relief effort, allowing for feedback from specialists in the field.

The choice of a man-made trigger like cyber-terrorism in an area typically not considered highly threatened enables the simulation of events that are less planned for, requiring collaboration among experienced specialists. The scenario serves as a feature presentation of the entire PANTHEON development effort.

Stakeholders from different organizations, including first responders, municipal representatives, infrastructure providers, media, and healthcare workers, will participate in a table-top exercise with diverse units active in the field of DRR, cooperating to manage the effects simulated by the PANTHEON platform. The simulation's duration and scope will depend on participating organizations and the system's development status, allowing flexibility through adaptations to the scenario leading up to the final pilot.

6 SHOWCASED TECHNOLOGIES AND SYSTEM SPECIFICATIONS

6.1 SIMULATION

In the context of PANTHEON's Smart City Digital Twin environment, simulation activities rely on advanced technologies and system specifications to create dynamic and realistic virtual models of the project's two pilot cities, Athens, and Vienna. One fundamental technology in this context is the development and use of simulation engines that can replicate the behaviour of various city systems. These simulation engines, as sophisticated software platforms, are designed to leverage computational algorithms to model and predict the interactions between different elements of the city, such as traffic flow, energy consumption, and environmental conditions among many others, thus allowing PANTHEON's stakeholders to observe, simulate and analyse the pilot cities' behaviour under different scenarios. Some indicative open-source platforms that could be utilized for these simulations include MATSim, SUMO, MARS, UrbanSuite, CityGML, and GAMA, covering the wide range of agent-based modelling, system dynamics, and discrete event simulation.

Simulation techniques employed in PANTHEON's digital twin vary based on the aspects being modelled. Traffic simulations may utilize microscopic models that simulate individual vehicles and their interactions, while macroscopic models focus on overall traffic flow and potentially seem more appropriate for PANTHEON's needs. Energy consumption simulations may use system dynamics models to represent the interconnected nature of energy grids and consumption patterns. For the agent-based modelling technique, individual entities or agents within the city are simulated, allowing for a detailed examination of interactions and emergent behaviour. The exact and final choice of the combination of simulation techniques depends on each of PANTHEON's specific use cases and the level of detail required for accurate representation, which will be defined later on in the project.

Furthermore, the incorporation of machine learning algorithms in the proposed simulated engines should enhance the predictive capabilities of PANTHEON's digital twin use-case and what-if simulations. By learning from historical and real-time data, machine learning models could forecast future trends, identify patterns, and perform correlations, thus facilitating simulations for potential scenarios and use cases with the final goal of improving the early warning capacity of cities under the case of a disaster. The combination of both these technologies contributes to more informed decision-making processes by providing insights into the potential outcomes of interventions performed on the digital twin pilot models. In the context of simulations, machine learning algorithms can predict future scenarios based on learned patterns, enabling PANTHEON's stakeholders to anticipate specific outcomes and plan the next simulations accordingly. Classification algorithms, regression models, and clustering techniques can also be applied to PANTHEON's simulation domains, aiding in forecasting and anomaly detection.

6.2 VISUALIZATION

In the framework of the PANTHEON project and anticipated pilots, the visualization concept relies on cutting-edge technologies and specific system specifications to deliver a comprehensive representation of PANTHEON's modelled pilot cities, Athens, and Vienna. One crucial technology is the implementation of interactive dashboards, which provide a user-friendly interface for PANTHEON's stakeholders to access, monitor and analyse data. These dashboards enable real-time monitoring and data exploration, allowing stakeholders to customize views based on their specific interests and responsibilities.

As another crucial technology, geospatial mapping plays a central role in the digital twin's environment visualization, offering a spatial context for data representation. Through the integration of geographic information systems (GIS), cities can map various features onto the digital twin, including infrastructure, transportation networks, and environmental data. GIS provides the spatial framework for both simulations and visualizations, as the geographic context offered is essential for understanding how simulated events and changes manifest in different locations within PANTHEON's pilot cities. The combination of GIS data with simulation results enhances the realistic representation of the digital twin. GIS contributes to the accuracy of spatial relationships, and simulations provide dynamic information about how these spatial elements evolve over time. PANTHEON's simulations generate data that are then integrated with GIS and can be visualized in a way that supports further decision-making. The stakeholders and end-users are able to use the visualized information to analyse the impact of different scenarios, evaluate potential interventions, and make informed decisions on how to manage and respond to emergency situations. The synergy between simulations, visualization, and GIS contributes to a comprehensive understanding of the digital twin's dynamics. Stakeholders can explore not only the numerical results of simulations but also see how these results manifest in the physical and spatial context of PANTHEON's pilot cities. In the same context, visualization tools incorporate GIS functionalities, allowing the stakeholders to interactively explore and analyse the digital twin. This interactive exploration can include zooming into specific geographic areas, overlaying simulation results, and dynamically adjusting parameters for real-time feedback.

Moreover, time-series charts are essential for tracking and analysing temporal trends in PANTHEON's proposed framework. These charts will allow stakeholders to observe how key metrics evolve over time, facilitating historical analysis and trend identification. By monitoring traffic, energy consumption, and environmental condition patterns, the time-series charts shall contribute to a dynamic and informed decision-making process and will feed the proposed machine learning techniques to be applied both in the simulation developments and in the development of the digital twin. Complementary to the time-series charts, heatmaps provide an effective means of visualizing data density and spatial patterns within PANTHEON's digital twin. By representing the concentration of activities or conditions across different areas of the pilot cities, heatmaps offer a valuable tool for identifying hotspots and trends. This technology aids in optimizing resource allocation and urban planning by highlighting areas that require specific attention or intervention.

In terms of system specifications, the implementation of robust computing infrastructure is essential. High-performance servers and cloud-based platforms are necessary to support the computational demands of processing and rendering the above-mentioned diverse data sets, ensuring the responsiveness and efficiency of PANTHEON's proposed platform. Such specifications enable the seamless integration of data from various sources, guaranteeing that the digital twin remains up-to-date and capable of consuming the aggregated input data streams. Furthermore, security measures are equally essential in the system specifications for the visualization framework of the PANTHEON project. Encryption protocols safeguard sensitive data, and access controls ensure that only authorized PANTHEON stakeholders can interact with or modify the digital twin. Within these encryption protocols, the PANTHEON project could include SSL/TLS encryption, Secure Sockets Layer and its successor, Transport Layer Security, to encrypt data in transit between users and the proposed PANTHEON digital twin platform, Data-at-Rest encryption to protect stored data on servers or databases by preventing unauthorized access in case of a breach or physical theft of storage devices, as well as End-to-End encryption to maintain the confidentiality of sensitive information by ensuring that data remains encrypted throughout its entire journey, from the server to the end-user's device. Considering access control security measures, the PANTHEON project could include Role-Based Access Control, which is a common method where users are assigned roles with specific permissions. In PANTHEON's digital twin platform, administrators, planners, and other stakeholders may have different roles with varying levels of access to data and functionalities. Additional and potential access control measures include Multi-Factor authentication, which adds an extra layer of security by requiring users to provide multiple forms of identification before gaining access, as well as the data privacy safeguards of Anonymization, involving removing identifiable details for persons, locations, and infrastructure, or replacing them with artificial identifiers, and Data Minimization, involving collecting only the necessary data and retaining only the minimum amount of data required for effective visualization, analysis, and simulations.

Programming languages, techniques and frameworks that are utilized for implementing the bespoke visualization and user interface architecture include Python, PHP, R, Bootstrap, React, jQuery, Grafana, D3.js, Plotly, Dygraphs, Leaflet, PostgreSQL, as well as the cloud-related Apache open-source solutions such as Kafka, Hadoop, Spark, Storm, Flink, RabbitMQ, Solr, and Elasticsearch. A design showcase of the proposed visualization framework can be seen in Figure 2.

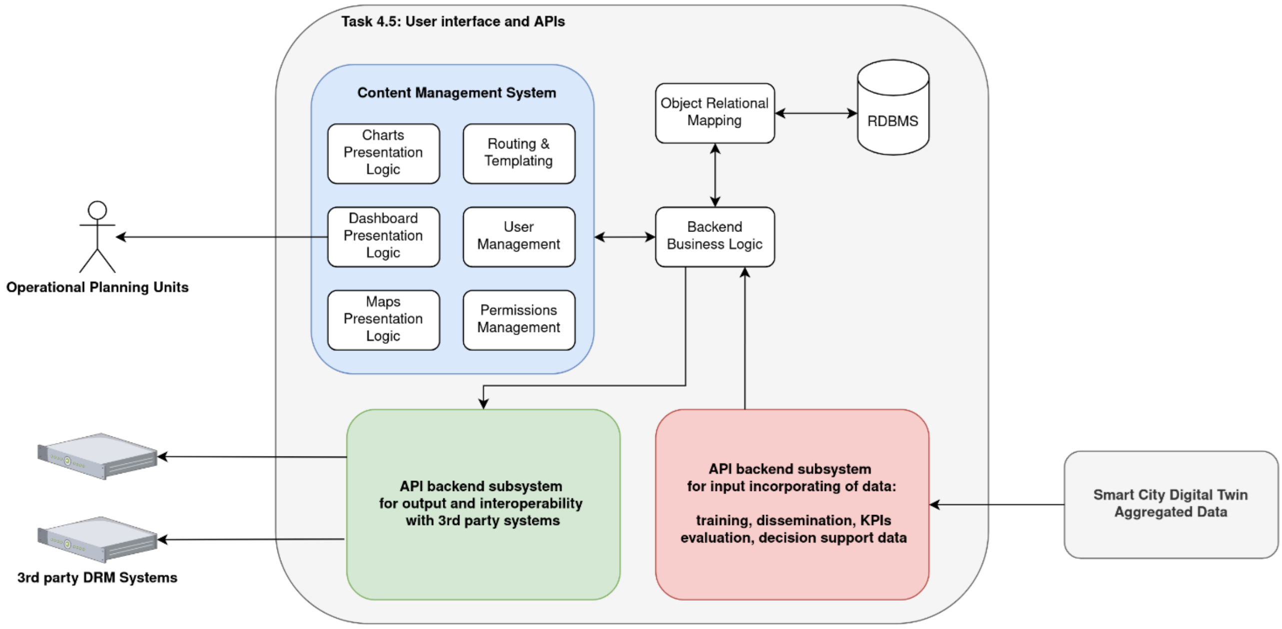

Figure 2 UI and Visualization Framework for PANTHEON

6.3 DRONE TECHNOLOGY

6.3.1 INTRODUCTION

Drone systems, or more precisely Unmanned Air Systems (UAS), are becoming more and more integrated in real operations. They offer good capabilities with a low price compared to traditional airplanes for many applications. However, their utilization is still limited by existing regulations that are quite conservative for safety reasons.

The UAS are composed of 3 components:

- The Unmanned Aerial Vehicle (UAV) which is the flying platform equipped with payload(s),
- The Ground Control Station (GCS) that prepares and controls the missions of the UAV,
- The data link (Ground-Air-Ground data link) to connect the UAV to the GCS and offer a bi-directional capability to pilot the UAV and to receive the data gathered by the UAV sensors.

There is a very large variety of UAS, ranging from micro- and mini-drones with a short range (< 30 minutes) and a limited payload capability (a few kg max) and that have a very local use up to HALE (High Altitude, long Endurance) and MALE (Medium Altitude, Long Endurance) that can fly during days and ensure a permanence in a specific area. The commercial offer in terms of drone systems is very wide nowadays, and encompasses many various technologies.

6.3.2 CONCEPTS OF OPERATIONS

There are various Concepts of operations (CONOPS) for the UAS in the domain of Disaster Management. For the planning and preparedness phases, the UAS are used as a modelling tool, together with satellites and traditional airplanes. They are especially useful to perform precise 3D-modelling when there is a need to fly at low altitude and close to the elements that will be modelled.

For the early warning phase, due to the absence of crew on board, the drones can be used to offer a permanent surveillance (24/7) to detect different types of events. They are presently widely used to detect fires very early and improve the traditional reaction delay which is often the cause of un-controlled fire events.

For the response phase, the UAS can be used for different applications, 1. Quickly performing the damage assessment to dimension and precise the needed response, 2. Area monitoring to cover the area of operations, 3. Local surveillance or detection in support of first responders 4. Specific operations (e.g. fire extinguishers) or 5. Transport of payloads to victims (food, medicines, etc.).

For each type of missions, the UAV can be equipped with various payloads corresponding to the user needs. In general, the typical and classical payload is a camera, but more specific sensors can be carried (chemical detectors, LiDARs (Light Detection and Ranging), gas detection, etc). However, the use of UAVs is not limited to sensors, but also transportation systems.

6.3.3 DRONE SYSTEMS DESCRIPTION

UAV

The UAV (flying platform) is composed of an aircraft, the navigation system, and the payload. The aircraft can be fixed wing, Vertical Take Off or Landing (VTOL), or hybrid, but different solutions are already available on the market, see some examples in Figure 3. The aircraft is described by its characteristics and performances.

EXAMPLE OF A QUADROTOR – DJI MAVIC PRO

EXAMPLE OF A HEXACOPTER – CUSTOM BUILT MODEL

EXAMPLE OF AN OCTOCOPTER – CUSTOM BUILT MODEL

ONE OF THE MOST POPULAR MULTIROTORS ON THE MARKET– DJI PHANTOM MODEL

Figure 3 Examples of different types of UAVs (source: https://www.airsight.com/)

The navigation system(s) is the subsystem that enables the navigation of the platform in automated, semi-automated or piloted mode. Depending on the availability or note of a Global Navigation Satellite System (GNSS, like GPS), the navigation system can be direct or hybrid (combined with other methods like terrain identification with 3D-models). In most cases, the preferred navigation is automated mode which is more precise and reliable than manual pilotage and of course reduces the human workload and the risk of errors.

The typical payload is a sensor, but it can also include transportation systems. In most cases, the main payload is a camera (EO/IR - Electro-Optical/Infra-Red- is preferred in general), but more specific sensors can be carried (chemical detectors, LiDARs, gas detection, etc). On larger UAVs, different types of radars can also be carried. Some UAVs can now be equipped with fire-extinguishers or food/medicines for the victims, and even technology for the evacuation of victims.

In order to simulate a UAV, the characteristics and performances of the platform need to be known and characterized. The computation of the sensors' footprint depends of course on the characteristics of the sensor(s) and the position and altitude of the platform.

GCS

The GCS is the workstation from where the UAV is controlled by the mission operator or by a non-human system (see Figure 4). The GCS is used to prepare the mission of the UAV and sensors (if not done upstream), but mainly to control the mission, verifying that the mission conforms to the plan and re-task if necessary. The GCS also incorporates the tools to monitor and exploit the data gathered by the UAV during its mission.

Figure 4 Real example of a GCS (source: https://hse-uav.com/)

The mission is prepared as per the tasking orders received from the Command and Control Link (C2) or the tactical commander. The data are exploited with the relevant tools (e.g. computer vision sub-system). Depending on the capability of the UAV payload and user needs, data exploitation can be done in the GCS (during or after the mission), or on board if the data processing system is embarked in the own UAV.

Data Link

The data link refers to the mean of communication between two (or more) connection points. In the case of drones, it refers to the communication channel between the GCS and the own UAV. The data link characteristics have to be taken into account to prepare the missions of the UAV since some characteristics are not valid for some specific scenarios. Based on radio technologies, the essential characteristics are:

- The frequency (in particular to avoid interferences with other systems),
- The range (depending on the power of the emitter/receiver and antennas capabilities),
- The bandwidth (uplink and downlink to pilot the UAV and receive its data at GCS level).

The mission should not be performed outside the range of the data link and the bandwidth needs to be sufficient to exchange the messages between the UAV and the GCS.

UAS integration

The different components of the UAS must be smartly selected and integrated. In the case of operations, the UASs are tasked as any other resources by the C2. The GCS has therefore to be integrated (or at least connected) with the C2 and the C2 sends the tasking orders and in return, the GCS sends the results of the mission whatever they can be (data, mission reports, etc).

In the case of micro or mini-UAVs, the systems can sometimes be operated directly by the first responders in the field through a tablet or a smartphone because the integrated system is commercially available for some specific tasks.

Swarms

For some types of operations, swarms of drones can be needed (see Figure 5 for a depiction of a drone swarm).

Figure 5 Example of swarm of drones

The swarms can be geographical (area shared in sub-areas) or collaborative (several drones collaborating in the same airspace). In this case, there is a need to have a Generic Ground Control Station (GGCS) to manage the swarm through relevant algorithms (especially for collaborative swarms) and data link protocols.

6.4 SENSOR DATA AND INTERNET OF THINGS

In order to obtain a complete overview of the areas of interest and to be accurately represented in the digital twin environment, local micro-climate and environmental conditions must be monitored/observed and the corresponding data must be acquired/harvested. In that sense, in the framework of the PANTHEON project and its pilots, proprietarily developed IoT-based weather stations will be deployed in each of the specific pilot sites/areas. These weather stations are equipped with a variety of sensors, able to observe local micro-climatic conditions through the measurement of specific environmental parameters, such as:

- Solar Radiation
- Wind Vector (speed and direction)
- Air Temperature
- Relative Humidity
- Liquid Precipitation

Table 2 lists the technical specifications of the sensors measuring the aforementioned parameters.

Apart from the specific IoT sensors, the weather stations include all the needed telecommunications equipment to wirelessly transmit the acquired data to a cloud platform (FINoT®; FINoT Platform, n.d.), suitable for data management and processing. The transmission is achieved by using a wireless gateway (able to gather, store and transmit the data), embedded with equipment for wireless transmission by both NB-IoT (NarrowBand-IoT; GSMA - Sign In, 2019) and IEEE (Institute of Electrical and Electronics Engineers) 802.15.4 (IEEE SA - IEEE 802.15.4-2020, n.d.) standards, as listed in Table 3. The whole procedure is graphically depicted in Figure 6.

Table 2 List of IoT-based sensors and their technical specifications

Sensors and Specifications

Sensor	Range	Resolution	Accuracy
Solar Radiation	0-2000 W/m^2	0.2 W/m^2	-
Wind Speed	0-80 m/sec	0.01 m/sec	±0.03 m/sec
Wind Direction	0-360°	1°	±2°
Air Temperature	-40 °C to +125 °C	0.1 °C	better than ±0.4 °C
Relative Humidity	0-99.9 %	0.1 %	±2 %
Liquid Precipitation	-	0.2 mm	±0.2 mm

Table 3 Communication types and their specifications

Communication Type Specifications

Communication Type	Standard/Protocol	Frequency bands
Mobile Broadband	LTE CAT (Long Term Evolution Category) NB2 (NB-IoT)	B1/B3/B5/B8/B20/B28
6LoWPAN (IPv6 over Low-Power Wireless Personal Area Networks)	IEEE 802.15.4	2.4-2.48 GHz

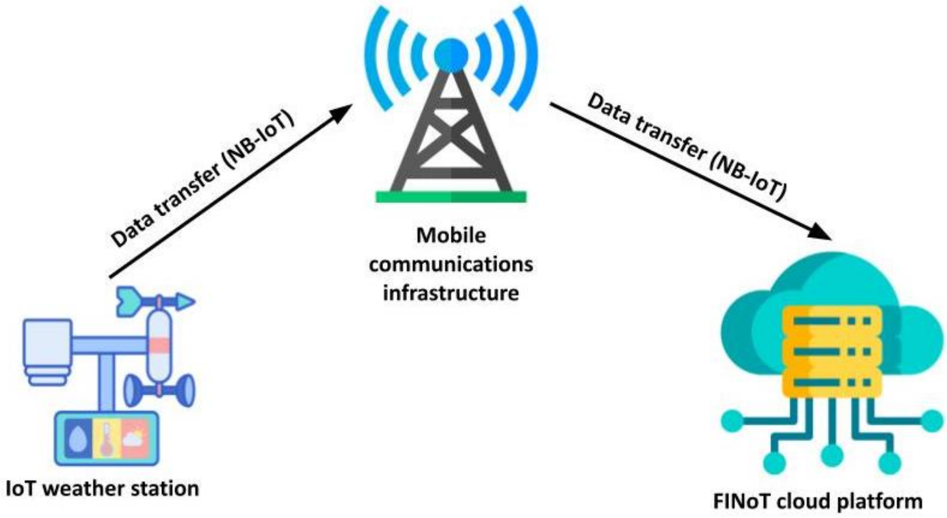

Figure 6 Data transmission from the in-situ IoT weather stations to the cloud platform.

Therefore, the environmental data are gathered/harvested by the IoT sensors of the weather station and subsequently sent to the FINoT cloud platform through the gateway, where all the management and processing takes place. Subsequently, these data can be sent to the PANTHEON platform by means of an API (Application Programming Interface), already developed as a part of the FINoT platform, which allows the data access and acquisition from third parties, such as the PANTHEON platform (see Figure 7).

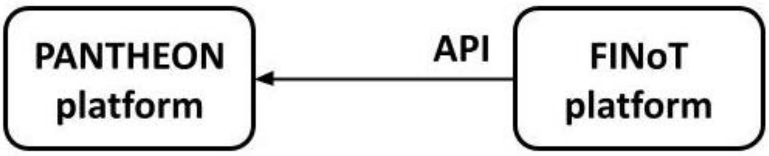

Figure 7 Cloud platform communication and data exchange through an API.

Thus, the local weather parameters data, which will be acquired and processed, will be provided to the PANTHEON platform, as input to the Smart City Digital Twin (SCDT), by offering a representation of local environmental conditions, important in the complete digital representation of the pilot site, as part of the digital twin.

7 CONSIDERATIONS FOR THE EVALUATION OF OUTCOMES

As stated in previous deliverables and in previous sections of this report, the PANTHEON consortium has identified four Use Case Scenarios (UCS), two for each pilot region (Athens and Vienna). Therefore, PANTHEON will develop four different versions of its system, implementing end-user feedback in each of them. The outline of these versions can be seen in Table 4.

Table 4 Use Case Scenarios and versions of PANTHEON system

Use Case nº	Use Case Scenario	PANTHEON System version
UCS1	Wildfires in Athens	V1
UCS2	Earthquake in Athens	V2
UCS3	Heatwave in Vienna	V3
UCS4	Man-made disaster in Vienna	V4 (final version)

Each version of the system will follow an evaluation cycle consisting of 3 distinct phases, which has been extracted from DUET Project (Hemetsberger et al., 2021) and adapted to PANTHEON (see Figure 8):

- **Phase 1 – End user participation.** In this phase, the end-users selected for each use case will test the respective versions of the PANTHEON system. Before using the system, the technical managers of each UCS will explain to the participants the main features of the system as well as the expected results and expectations.

- **Phase 2 – Evaluation of results.** In each cycle, an evaluation report will be produced on the results of each pilot test. This report will briefly describe the following aspects of the test:
  - Types of users involved in the test (firefighters, doctors, civil protection, etc.) and the number of participants for each UCS.
  - Methods and tools used to test the technology, which may be quantitative or qualitative, as explained below.
  - The main results of the pilot test, i.e. the input and views of the end-users.

- **Phase 3 – Implementation of the results**. The aim of the implementation phase is to confirm the main findings of each pilot test and to propose appropriate actions to meet the needs and suggestions of the end-users. The categories of improvement actions will be as follows:
  - Add to the system: features and functionalities not foreseen by the system and identified by the users as relevant and/or necessary.
  - Remove from the system: features and functionalities provided in the system that have been identified by users as unnecessary or not relevant.

- o Improve the system: features and functionalities provided by the system that have been identified as relevant but are unclear and/or inadequate.
- o Fix the system: features and functionalities provided by the system and identified by users as relevant, but which were rated as not or not very functional.

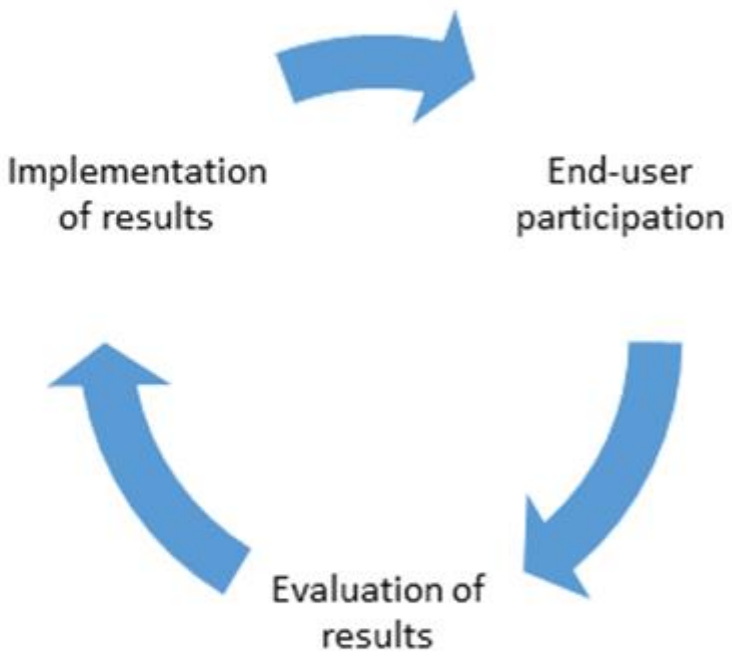

Figure 8 PANTHEON evaluation cycle

7.1 METHODS OF ASSESSMENT AND INCLUSION OF RECOMMENDATIONS FROM THE END-USERS

In the field of operational scenarios, user satisfaction is of paramount importance, and end-user input in assessing and improving operational frameworks is necessary to ensure this. Traditional methods often fail to capture the nuances of users, leading to a shift towards inclusive approaches. Evaluating operational scenarios and incorporating recommendations from end users is a critical aspect of ensuring that systems, processes or services meet user needs and expectations. Authors such as Nielsen (1994), Maguire (2001), and Goodman et al. (2012), point out several methods and steps for evaluating operating scenarios and incorporating end-user recommendations:

- conducting surveys to collect end-user feedback on their experiences with current operational scenarios, including questions that assess user satisfaction and suggestions for improvement of the project,
- organizing focus group discussions with a representative sample of end users,
- identifying areas for project improvement based on real observations,
- identifying areas where users encounter difficulties when working with pilot test scenarios,
- development of prototypes of proposed changes or improvement of operating scenarios,
- testing prototypes with end users with feedback on proposed solutions.

Using these methods and considering the recommendations of end users allow pilot projects to be designed in accordance with the needs and expectations of users.

Involving end users in the pilot tests requires a strategy. Following the methodology of Hemetsberger et al. (2021), this strategy can be divided into 4 different phases:

- **Phase 1 – Identification of potential users.** In this phase, the potential users that could be involved for each use case are identified. It is possible that there will be different relevant users for each use case, so it will be decided whether to pilot test together or separately.

- **Phase 2 – Contact potential users.** The leaders of each pilot will contact the potential users and invite them to a workshop (online or face-to-face) to explain the project, and in particular the PANTHEON system. If they agree to take part in the pilot test, they will be sent the relevant informed consent form. Finally, the date, place and time of the test will be fixed.

- **Phase 3 – Pilot test.** The consortium managers will prepare the pilot test for each usage scenario to allow users to interact and test the PANTEON system.

- **Phase 4 – Collecting feedback and input.** After each pilot test, the managers will carry out the various methods of gathering feedback and input. A variety of evaluation methods will be used, including, and combining both qualitative and quantitative methods. The methods may vary depending on the objectives of each pilot test. Qualitative methods include interviews (structured and/or semi-structured), focus groups and workshops. Quantitative methods will mainly include questionnaires.

One way to measure user satisfaction is the Post-Study System Usability Questionnaire (PSSUQ) validated by Lewis (1995). It is shortly described here as an example of how the evaluation of the pilots may be conducted. The questionnaire should be given to the participants after each test and they can only answer it once. It takes approximately 10 minutes to complete. The questionnaire starts with questions gathering socio-demographic data of each participant, which is followed by the PSSUQ - a 19-item tool designed to assess user satisfaction with the usability of the system. Each item has a 7-point scale ranging from strongly agree (1) to strongly disagree (7), with the option of not applicable (N/A) outside the scale. A psychometric evaluation of the questionnaire was carried out to test its reliability, validity, and sensitivity (Lewis, 1995). The questionnaire can be found in Chapter 11 - Appendix.

8 TIMELINE

It is planned to conduct the first pilots, taking place in Athens, in Month 33 of the project (September 2025). The second pilot taking place in Vienna is planned for M35 (November 2025). It is planned to submit D8.2 and the concrete execution plans shortly before the execution of the first pilots. The full timeline can be seen in Figure 9.

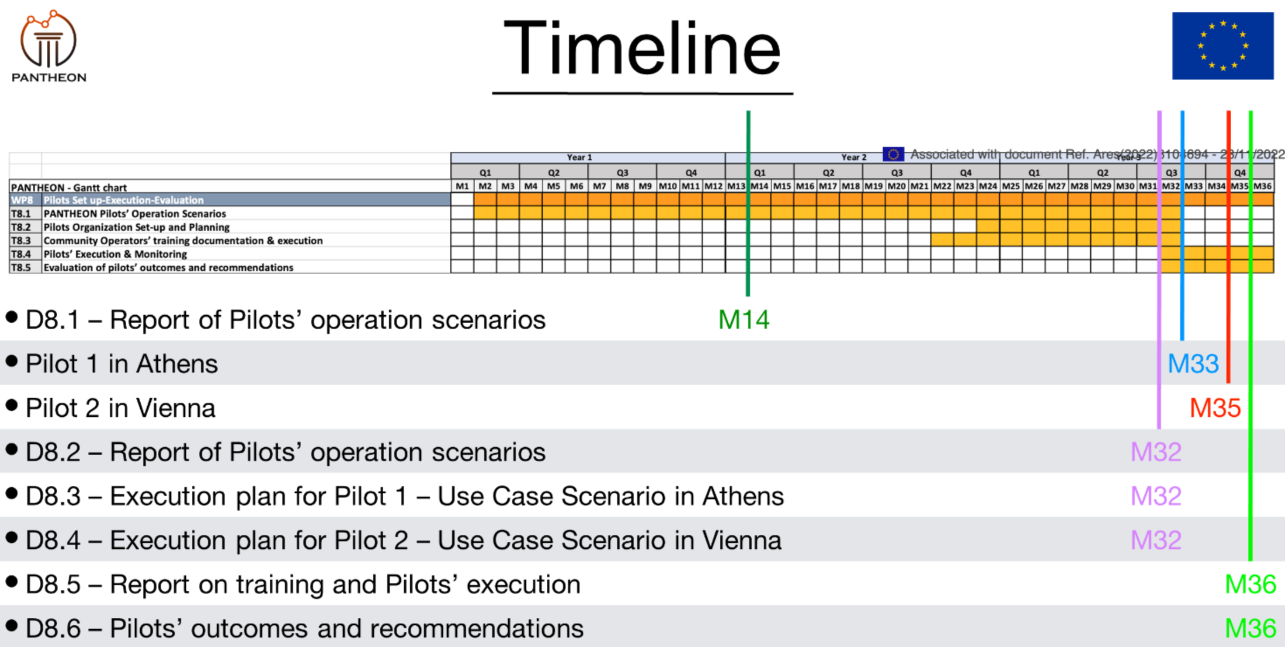

Figure 9 Timeline for the pilots

Task 8.1 has a long running time to be able to collect all the other work packages' input and support the integration of said efforts from the other work packages feeding into the pilot's organization, documentation, execution, and finally evaluation. This deliverable shows the cross-linkages of ongoing discussions and workshops and shall create a guidance framework for the system's development during the months before the pilots.

9 CONCLUSION

This Deliverable gives a preliminary overview of the planned pilots for testing the PANTHEON platform. The PANTHEON project has the goal of helping to create disaster resilient urban communities. In this context, a Smart City Digital Twin will be created and piloted, which is ultimately meant to be used in disaster resilience building and disaster response. The pilot scenarios were derived from work done in WP2 which included participative methods such as workshops and expert interviews to determine relevant hazards and design recommendations for this system. After determining the most relevant hazards for the pilot regions in T2.2 (Triantafyllou & Apostolopoulou, 2024), the following scenarios were chosen for the pilots: Wildfire and earthquake in Athens, and heatwave and a man-made disaster modelled after a real-life exercise in Vienna. Detailed descriptions of the pilot scenarios as well as the technological capabilities of the system can be found in D3.6 (Karamousadakis et al., 2024).

Following the categorization used in D3.2 (Bittner et al., 2023), the scenarios were allocated either to showcasing the system as a planning and early warning tool (earthquake and heatwave scenarios) or as a training and exercise tool (wildfire and man-made disaster). In detail, this means that the PANTHEON system should facilitate training and exercises of first responders for a wildfire caused by a cyber-terrorism attack and provide planning and early warning to enable the development of emergency plans for a heatwave happening in the metropolitan area of Vienna.

The heatwave scenario will focus on the problem of resource depletion of first responder organizations in a simulated case of a heatwave causing a spike in ambulance calls due to heat strokes and other related health problems. The scenario will help first responder organisations to train for reprioritization of transports as well as switching to a triage system.

The man-made disaster scenario will be based on a real-life exercise carried out as part of another project. The scenario will include a wildfire caused by a cyber-attack on a power plant. This scenario will especially include cascading effects of infrastructure failures and flows of people.

For the Athens pilot, the wildfire scenario will showcase the “training and exercise”-function of the system, and in the earthquake scenario it will be used as a planning and early warning tool. The wildfire scenario simulates a wildfire in the north western suburbs of Athens and includes, among others, a threat to transportation hubs and energy facilities. The PANTHEON system should help first responders such as the fire brigade to better assess the situation and make informed decisions, considering possible cascading effects of possible affected gas pipelines and roads so they know better where to prioritize their resources. Similarly, cascading effects on infrastructure failures and multiple disrupted failures will also be included in the earthquake simulation, which will simulate an earthquake caused by an active fault at the SW slopes of the Parnitha mountain, with a magnitude of 6.3 R. First responders can then give priority to restoring particular infrastructure nodes that are the most important due to potentially setting off several cascading consequences.

The PANTHEON system as a training and exercise tool can help to replace or supplement the current gold standard of practical field exercises for first responders. PANTHEON will provide simulations that can be used to create an exercise-like feedback loop, which includes a scenario that is presented to the trainees, the collection of their responses, and the incorporation of the trainees’ actions and the effects of these actions on the simulation. The use of the PANTHEON system as an early warning tool should help first responders to optimize their allocation of resources and plan the shortest route to a disaster, therefore ensuring an efficient response to an emergency. The simulation capabilities of PANTHEON will enable users to optimize their planning accordingly, presenting a dynamic disaster landscape and including various relevant data in form of a Digital Twin, such as weather data, drone footage, satellite imagery, infrastructure data, and data on vulnerabilities, including possible effects of a hazard on the road network. Furthermore, the system will be able to simulate the effects of multiple infrastructure failures and compound events.

The PANTHEON system will use several technologies to achieve this aim, which will be tested during the pilots. Firstly, the simulation capabilities of the system will be tested, potentially using open-source platforms such as MATSim or SUMO. The system may use a combination of different models and techniques, such as microscopic models, e.g. for simulating individual vehicles, macroscopic models, e.g. for simulating a whole city and its infrastructure, or agent-based modelling, simulating individual entities. In addition, machine learning may be incorporated into the system. Furthermore, visualizations will be used to depict the Digital Twins, including geospatial mapping of crucial infrastructure onto maps of the pilot areas via GIS. Additionally, the simulations should include a user-friendly dashboard on which users may manipulate parameters, allowing them to interact with the visualized Digital Twin and the visualized effects of different hazard scenarios. Visualized data will include heatmaps of certain activities and conditions, highlighting areas that require special attention. The third technology to be showcased is drone technology. Drones or UAS can be used as precise 3D-modelling tools, they can provide surveillance for early detection of different events (e.g. fires), they can be used for damage assessment or area monitoring in the acute response phase of a disaster, and they can be used to carry sensors, cameras, or other objects. In the PANTHEON pilots, it is planned to include drones as a simulatable resource. Lastly, sensor data and IoT technology will provide some of the data necessary for the simulations and the Digital Twin. For this purpose, IoT-based weather stations will be installed in each of the designated pilot areas, collecting data on various parameters such as solar radiation and air temperature. It is planned to send the data from the weather station to the FINoT platform, where it will be stored, managed, and processed, and then further sent to the PANTHEON platform via an API.

The pilots will be carefully planned and evaluated, including collecting data on the success of the different scenarios and the different functions of the system which will be showcased. To ensure an ideal execution of the pilots, the participating actors/stakeholders will be trained beforehand in workshops, and pilot guidelines and user's handbooks will be provided. Furthermore, end-user feedback in the form of questionnaires, interviews, and observations will be collected and published in the form of end-user reports. This feedback will then be used for improving the system and fixing possible errors. This work will be done in the other Tasks within WP8. The first pilot, which will take place in Athens, is planned for M32 (mid 2025), and the second pilot, taking place in Vienna, is planned for M35 (late 2025). The outcomes of the pilots and further recommendations will be published in a report at the end of 2025.

Taken together, the planned pilots and scenarios are supposed to showcase the diverse range and the many application possibilities of the PANTHEON system in making urban communities more resilient against disasters.

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11 APPENDIX

The Post-Study System Usability Questionnaire (PSSUQ)

Administration and Scoring. Give the PSSUQ to participants after they have completed all the scenarios in a usability study. You can calculate four scores from the responses to the PSSUQ items: the overall satisfaction score (OVERALL), system usefulness (SYSUSE), information quality (INFOQUAL), and interface quality (INTERQUAL).

Instructions and Items. The PSSUQ items use the same format as that shown for the ASQ. The questionnaire's instructions and items follow. This questionnaire gives you an opportunity to tell us your reactions to the system you used. Your responses will help us understand what aspects of the system you are particularly concerned about and the aspects that satisfy you. To as great a degree as possible, think about all the tasks that you have done with the system while you answer these questions. Please read each statement and indicate how strongly you agree or disagree with the statement by circling a number on the scale. If a statement does not apply to you, circle N/A. Please write comments to elaborate on your answers. After you have completed this questionnaire, I'll go over your answers with you to make sure I understand all of your responses. Thank you!

Overall, I am satisfied with how easy it is to use this system.
It was simple to use this system.
I could effectively complete the tasks and scenarios using this system.
I was able to complete the tasks and scenarios quickly using this system.
I was able to efficiently complete the tasks and scenarios using this system.
I felt comfortable using this system.
It was easy to learn to use this system.
I believe I could become productive quickly using this system.
The system gave error messages that clearly told me how to fix problems.
Whenever I made a mistake using the system, I could recover easily and quickly.
The information (such as on-line help, on-screen messages, and other documentation) provided with this system was clear.
It was easy to find the information I needed.
The information provided for the system was easy to understand.
The information was effective in helping me complete the tasks and scenarios.
The organization of information on the system screens was clear.
The interface of this system was pleasant.
I liked using the interface of this system.
This system has all the functions and capabilities I expect it to have.
Overall, I am satisfied with this system.