Community-Based Smart City Digital Twin for Optimised Disaster Risk Management Operations and Enhanced Community Disaster Resilience

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Introduction

The PANTHEON project aims to improve community resilience to disasters through the development of a community-based digital DRM platform using Smart City Digital Twin (SCDT) technology. In order to design and implement this technology in the pilot areas, the Attica region and Vienna federal state, the first year of the project focused on studying their contexts, including their most relevant natural and man-made hazards, their regulatory frameworks, the capacity and vulnerability of their communities, and existing ways to involve the most vulnerable groups in decision-making on disaster management issues. These results were the basis for the idea of the PANTHEON platform, which will provide a disaster visualisation and simulation tool for both crisis training and planning, using various data sources available in a smart city.

Methodology

The design of the PANTHEON system has been the result of a participatory design process in which potential end users have been directly involved. This approach is ideal for reducing the gap that often exists between users' needs and the products offered by industry. Once potential PANTHEON end-users have been identified, according to their different roles in a specific disaster situation, various research methods were used to understand their operational contexts, identify their needs and explore how the PANTHEON system could meet them. In addition to interviews and surveys, workshops were conducted using techniques such as Brainstorming, Timelines and Visualisation using the Walt Disney method. All of this, together with an extensive literature review, served as the basis for the design of the PANTHEON system.

PANTHEON Ecosystem

Figure 1 – PANTHEON approach for building disaster-resilient communities

1 – Analysis of CBDRM National and Regional Policies and Existing Platforms

We examined the legal context related to disaster and crisis management in order to align the PANTHEON system with the civil protection framework of the pilot areas. In the Attica Region, civil protection strategies have been developed, related to specific hazards such as the action plans for the management of wildfires, earthquakes, floods, frost and snowfalls, as well as the plan for the adaptation to climate change. For the province of Vienna, the national civil protection strategies are implemented i.e., the Austrian Security Strategy, the Austrian Cyber Security Strategy, the Masterplan Austrian Programme for Critical Infrastructure Protection, the National Crisis and Disaster Management, the Austrian Strategy for Adaptation to Climate Change, the National Heat Protection Plan and the Flood Risk Management.

2 – Regional Multi-Hazards/Risk Data and Assessment

Table 1 & 2 show the risk mapping and assessment of the most relevant natural and man-made hazards, affecting the pilot areas of Vienna and Attica region in terms of impact and likelihood of occurrence, which developed a basis for the PANTHEON system.

Matrix of qualitative risk assessment in the Attica Region		Impact				
		Very Low	*Low*	*Moderate*	*High*	*Very High*
Likelihood	*Almost Certain*	---	---	Heatwaves	---	**Wildfire**
	Likely	---	---		---	---
	Possible	---	---	Cyber-attack	**Earthquake** Flood	---
	Unlikely	---	Landslide	Terrorist attack	---	---
	Rare	---	---	---	---	---

Matrix of qualitative risk assessment in the Fed of Vienna		Impact				
		Very Low	*Low*	*Moderate*	*High*	*Very High*
Likelihood	*Almost Certain*	---	---	---	---	---
	Likely	---	---	---	**Heatwaves**	---
	Possible	---	Earthquake Flood	Wildfire	**Terrorism Cyber-attack**	---
	Unlikely	---	---	---	---	---
	Rare	---	Landslide	---	---	---

Table 1 & 2 – Risk assessment matrices of the PANTHEON pilot areas

3 – Community Vulnerability and Capacity Assessments

A set of indicators was developed to assess the vulnerability and capacity of communities in the pilot areas. Vulnerability indicators were defined as factors that place certain communities at increased risk of injury, death or financial ruin in the event of a disaster. Capacity indicators, on the other hand, refer to the characteristics or strengths of a community that enable it to reduce and better manage disaster risks. Table 3 shows a sample of some of the vulnerability indicators produced by the project.

Life stage-related	Advanced age (% people + 65 y/o)
	Young age (% people -15 y/o)
Health-related	Mental/Physical health (% people with mental/physical condition)
	Mobility (% people with known mobility problems)
Social connection-related	Migration background (% first generation immigrant households etc.)
	Social isolation (% of single-person households in the area)
Resource-related	Financial resources (Median income of inhabitants)
	Potentially affected agricultural areas (% of the region being farmed land)
Exposure and protection-related	Population density (Nº of inhabitants per km^2)
	Homelessness (% of unhoused people)
Knowledge and awareness-related	Lack of disaster awareness/education (Nº of disaster trainings x 1000 inhab.)
	Lack of familiarity with local environment (% people without familiarity)

Table 3 – Sample of the Vulnerability indicators devised for the focus regions

PANTHEON System

Having examined the hazards that can affect the two areas, as well as the existing legal framework and civil protection strategies, the next step was the identification of a set of potential applications, against which the developed Smart City Digital Twin system will be tested and evaluated. Among a number of applications, from the pre-catastrophic to the recovery phase, the following two were selected which fall under the prevention/preparedness phases:

Before a disaster	A	Planning and early warning according to simulations	Models and simulations based on big amounts of data are being used to estimate the evolution of disaster scenarios thus supporting the development of emergency plans, giving prognosis or serve as early warning systems through continuous monitoring.
	B	Training and exercises	Bridging the gap between expensive large-scale exercises and abstract table-top exercises, the SCDT facilitates cross-organisational trainings increasing the mutual understanding of needs during disaster response and shedding light on blind spots.

Table 4 – PANTHEON established applications

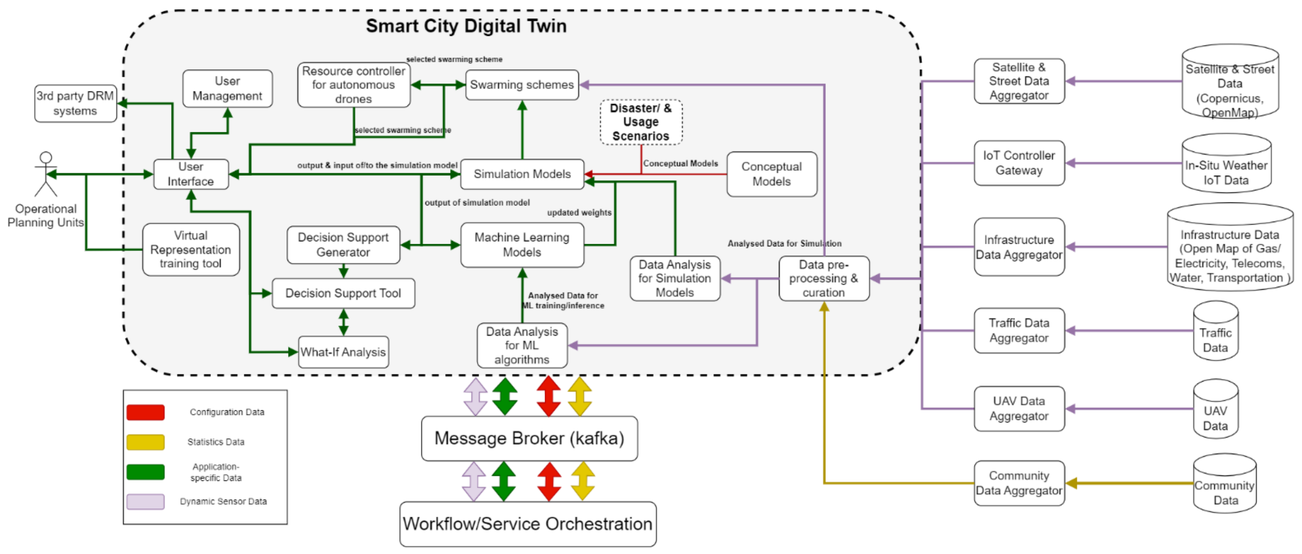

Figure 2 – PANTHEON functional architecture

Figure 2 analyses the functional view of the PANTHEON system. It comprises various data aggregation components (Satellite, UAVs, Critical Infrastructures, Weather IoT, Traffic, and Community) along with data curation, pre-processing, and analysis components. Advanced ML algorithms process this data for use in Smart City Digital Twin (SCDT) simulations. Additionally, the system features a User Interface, Decision Support System, What-If analysis component, and resource controller for autonomous drones. Key capacities of PANTHEON include realistic representation of real-world conditions in simulations and visualization capabilities through the UI. The simulations utilise data-driven graph representations which evaluate dependencies within the road network and can generate dependency risk scores based on impact and likelihood values, facilitating the visualization of the disaster and its impact on the road network. The UI enables interaction with end-users and DRM stakeholders, displaying simulation results and 2D representations of the area of interest, and providing a virtual representation tool for user training (e.g., first responders).

Use Case Scenarios

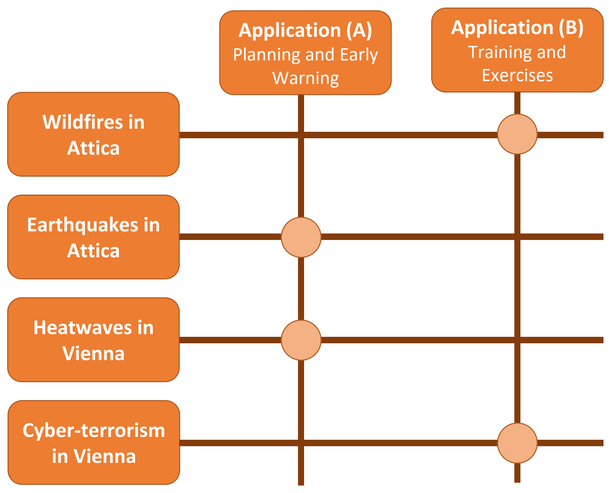

Figure 3 – Connection between PANTHEON system applications and its use cases

After defining the applications of the PANTHEON system through a participatory design process involving its potential end-users, each of them was mapped to the disasters previously defined as the most relevant in the area in terms of impact and likelihood. As shown in Figure 3, application A was selected for earthquakes in Attica and heat waves in Vienna, while wildfires in Attica and cyber-terrorism in Vienna were linked to application B. Based on this, usage scenarios were created, which were further elaborated into functional steps or use cases representing the flow of operations to be followed by the user in the PANTHEON platform for each scenario. The flow of the use cases is represented in Figure 4. Thus, after registration and authentication, the user must set certain parameters relating to the specific disaster to be simulated and the assets available to his organisation for this type of crisis. Once the simulation has started, the system will process the cascading effects of the disaster and then provide the user with insights and decision support.

Figure 4 – General flow of use cases

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