PANTHEON

Community-Based Smart City Digital Twin Platform

for Optimised DRM operations and Enhanced Community

Disaster Resilience

D3.1

PANTHEON TECHNOLOGY ROADMAP FOR DISASTER RESILIENT COMMUNITIES

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

DOCUMENT INFO

Deliverable Number	D3.1
Work Package Number and Title	WP3 – "PANTHEON Requirements, Participatory Design Process and Pilot Use-Cases Specifications"
Lead Beneficiary	KEMEA
Due date of deliverable	31/08/2023 (M08)
Deliverable type[1]	R – Document, report
Dissemination level[2]	PU - Public
Author(s)	John Tsaloukidis, Paraskevi Petsioti, Christina Gatsogianni, Eftichia Georgiou (KEMEA), George Stergiopoulos, Mike Karamousadakis (THL), Vassiliki Apostolopoulou (PRACTIN), Sotiris Nakos (INTEROPT), Otillia Bularca (SIMAVI), Christina Barrado (UPC), Jim Sharples (ENAC)
Internal reviewer(s)	Otilia Bularca (SIMAVI), Mike Karamousadakis (THL), Constanze Geyer (JOAFG)
Version - Status	1.4 – Final Document

TASK ABSTRACT

The present Deliverable "PANTHEON Technology Roadmap for Disaster Resilient Communities" is the outcome of T.3.1 "Technology Roadmap for PANTHEON Disaster-Resilient Communities building". The aim of this Deliverable is to provide an overview of the various technologies that will be utilised throughout the lifetime of the project and namely to present expected technical improvements and further development. In addition, the technological outcomes of specific research projects have been documented, with the scope of depicting the complementarity of PANTHEON with existing innovations.

[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

REVIEW HISTORY

Version	Date	Modifications	Editor(s)
1.0	02/08/2023	First draft	John Tsaloukidis (KEMEA)
1.1	11/08/2023	SIMAVI Review	Otilia Bularca (SIMAVI)
1.2	14/08/2023	THL Review	Mike Karamousadakis (THL)
1.3	21/08/2023	JOAFG Review	Constanze Geyer (JOAFG)
1.4	28/08/2023	Final Document	John Tsaloukidis (KEMEA)

DISCLAIMER

Funded by the European Union. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or European Commission. Neither the European Union nor the granting authority can be held responsible for them.

Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
AI	Artificial Intelligence
ANN	Artificial Neural Network
AR	Augmented Reality
BIM	Building Information Model
CBDRM	Community-Based Disaster Risk Management
CBRNe	Chemical, Biological, Radiological, Nuclear, explosives
CC	Command and Control
CCA	Climate Change Adaptation
CCTV	Closed-Circuit Television
CES	Cascading Effects Simulation
CI	Critical Infrastructure
CIM	City Information Model
CNN	Convolutional Neural Network
CPA	Civil Protection Agency
DBMS	Database Management System
DCT	Disaster Community Technologies
DL	Deep Learning
DGM	Deep Generative Model
DRM	Disaster Risk Management
DRS	Disaster Resilient Societies
DSS	Decision Support Systems
DT	Decision Tree
EHR	Electronic Health Record
EU	European Union
FAS	Flood Alert System
GIS	Geographic Information System
GPS	Global Positioning System
HAZMAT	Hazardous Materials
HTTC	High Throughput Congestion Control
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technologies
IDDSS	Intelligent Disaster Decision Support System
IoT	Internet of Things
IT	Information Technology
KI-CoP	Knowledge Innovation Community of Practice
LCC	LINKS Community Center
LL	Living Lab
MBMS	Model Base Management System
NGO	Non-Governmental Organisation
NLP	Natural Language Processing
RMF	Resilience Methodological Framework
RNN	Recurrent Neural Network
RPAG	Risk Perception Action Gap
RPAS	Remotely Piloted Aircraft System
SAR	Search and Rescue

SCDT	Smart City Digital Twin
SMCS	Social Media and Crowdsourcing
SME	Small Medium Enterprise
SUDT	Social Urban Digital Twin
TMP	Traffic Management Point
TOE	Technology-Organisation-Environment
TRL	Technological Readiness Level
UAV	Unmanned Aerial Vehicles
UCSA	Urban Change Spatial Analysis
UCPM	Union Civil Protection Mechanism
UDT	Urban Digital Twin
UI	Urban Interface
UWB	Ultra-Wide Band
VOST	Virtual Operations Support Teams
VR	Virtual Reality
XR	Extended Reality

EXECUTIVE SUMMARY

This Deliverable is the outcome of Task 3.1 “Technology Roadmap for PANTHEON Disaster-Resilient Communities building”. The objective of the Task and the respective Deliverable 3.1 is to present technological advances, improvements and further development of specific technologies that will take place during the lifetime of the project. This Deliverable capitalises on the feedback gained from studies conducted by the European Commission and networking projects, which have highlighted gaps and challenges often confronted by first responders during response operations. PANTHEON aims to address, to a significant extent, these challenges by providing cutting edge technologies that will facilitate end users and increase their overall disaster management capacities.

The second part of this Deliverable is related to the selection of specific research projects, the documentation of their outcomes, namely the technological ones, and the correlation between these projects and PANTHEON. The aim of this mapping of projects is to highlight commonalities, complementarity and compliance of PANTHEON with existing innovations and initiatives. The list of projects included in this research is not exhaustive but indicative and consists of projects, either under the same call and topic as PANTHEON, or under a different topic but with outcomes related to the results that PANTHEON aims to deliver.

1. INTRODUCTION

Technology plays a significant role in the management of disasters, either natural or man-made. First responders heavily rely on technological systems and tools in order to increase their capacity regarding the four phases of the disaster management cycle, i.e., prevention, preparedness, response and recovery. Nowadays, a large variety of technological innovations exists, which provide end users with numerous capabilities, thus increasing their capacity to combat disasters and crises. There are technologies, which facilitate first responders' training such as Augmented Reality / Virtual Reality / Extended Reality / Mixed Reality simulation tools, Artificial Intelligence software for the modelling of various parameters and the evolution of specific situations, geolocation and GIS technologies for the management of personnel and assets, risk monitoring systems utilising both ground observations and high resolution aerial/satellite images, early warning systems, technologies for crowdsourcing and big data analysis, decision support and command and control systems, digital twin and smart city technology among others.

However, to increase the efficiency and the impact that technology has in disaster management it is important that products and innovations are in line with the demand from the end user's perspective. The Directorate-General for Migration and Home Affairs (DG HOME) of the European Commission conducted, in 2022, a study with the scope of depicting the current state of the safety and security related market across the EU. One of the main findings of this study is that there seems to be a gap between the two edges of the market i.e., the suppliers and the end users. In order to bridge this gap a capability driven approach is suggested (European Commission DG HOME, 2022). Such an approach comprises of:

- identification and definition of end users' capability gaps and challenges,
- communication between end users and suppliers, with the aim, the latter, to be aware of what the safety and security practitioners' needs are and to develop the appropriate technologies.

The aforementioned lack of a capability driven approach has been the focus of various research projects, e.g., FIRE-IN (FIRE-IN, n.d.) and MEDEA (MEDEA, n.d.), which bring together a wide range of safety and security stakeholders, foster interactions between them and facilitate information exchange, in order to align supply with demand. An event, organised jointly by the two projects, provided significant results regarding the technologies, which from the first responders' point of view, are considered crucial for the mid- and long-term future.

PANTHEON takes into consideration the outcomes of the DG HOME study as well as the results from stakeholders' interactions, under the framework of networking projects, and seeks to address this highly recognised need by delivering technologies of high importance for stakeholders, including first responders and Critical Infrastructure (CI) operators. This Deliverable builds upon two main pillars:

1. The description of technologies, which are expected to be developed and further improved throughout the lifetime of the project. Chapter 2 and its respective subchapters describe technologies related to smart city digital twins, AI models and simulations, Decision Support, assets management and risk monitoring systems, which are brought by the technical partners of the Consortium.
2. The identification of projects, which either have a similar topic with PANTHEON e.g., under the SU-DRS01-2018-2019-2020 "Human factors, and social, societal, and organisational aspects for disaster-resilient societies" topic, or have produced technological outcomes, close to the ones prescribed to be delivered by PANTHEON. The goal of this research is to highlight correlations and complementarity

of this project with existing innovations. Nine projects have been identified and described in the third section of this Deliverable.

Deliverable 3.1, with its high-level description of technologies to be developed within the context of the project, practically constitutes an introduction to the more technical Tasks and Work Packages, the implementation of which will shortly follow.

2. PANTHEON TECHNOLOGIES, POTENTIAL GAPS AND FURTHER DEVELOPMENT

Disasters are becoming increasingly complex. This fact is also subserved by climate change, which greatly affects the nature and impact of hazards. On the other hand, natural hazards affect industrial sites and establishments, the interconnection of which could lead to unprecedented consequences. Moreover, apart from natural processes, the human factor cannot be defied as actions of terrorism, sabotage and cyber-attacks on critical infrastructures are rising.

Effective crisis management is based on two main pillars, a) the deployment of resources and operational personnel following specific operational procedures and protocols, which are widely accepted and used by disaster management specialists worldwide and b) cutting edge technologies, which enable practitioners to deal with extreme situations and timely respond to emergencies. It thus becomes apparent that disaster management heavily relies on two types of solutions, the procedural and the technological ones. In addition, standardisation procedures focus on the development of standards which target either operational procedures, in order to facilitate and increase interoperability among different first responders' organisations, or technical specifications with the aim to achieve efficient communication between different systems and tools.

Different types of technologies exist and are currently being used by emergency management stakeholders, while, at the same time, new products are being developed and become available on the market. They include, inter alia, AI, sensors for the detection of fire, smoke and Chemical Biological Radiological Nuclear explosive (CBRNe) agents, AR/VR software for first responders' training and simulations, propagation models for fire and floods, decision support systems for the command posts, big data analysis systems for the integration and filtering of large volumes of information, early warning technologies, technologies for robust and resilient communications, smart city and digital twin systems. However, despite the broad range of solutions, gaps and challenges are still observed.

Significant results regarding the safety and security market all around the EU were produced by the EU security market study, the aim of which was to provide an overview and an in-depth analysis of the security technological roadmap in the EU as well as guidance and recommendations for the future. The EU Security market study was conducted by the European Commission Directorate-General for Migration and Home Affairs (DG HOME) (European Commission DG HOME, 2022).

Four research areas were explored for the study i.e., disaster resilient societies (DRS), resilience of critical infrastructure (INFRA), border management (BM) and the fight against crime and terrorism (FCT). In addition, feedback was collected by stakeholders, either from technological providers or from end users. A stakeholder catalogue was created with the aim of providing an overview of the active stakeholders in the security domain, at the regional, national and EU levels, at the time the study was conducted. As end users are considered the ministries, civil protection agencies, law enforcement agencies and first responders as well as research organisations. On the other hand, suppliers are considered large industries, security companies and SMEs, which develop technologies related to the safety and security domains.

According to the study, from 2015 till 2020, almost 53 billion € was spent for the procurement of security related technologies, although the numbers differ among the various studies conducted by different organisations. This provides evidence regarding the difficulty in the estimation of the total amount of money spent in the security market since different methodologies are followed. Moreover, it seems that during the same period, the biggest amount of money was spent on the INFRA-related research area, followed by the

DRS area. The following figure depicts estimations of money spent by the end users (demand-side) according to the four aforementioned research areas (BM, DRS, FCT, INFRA).

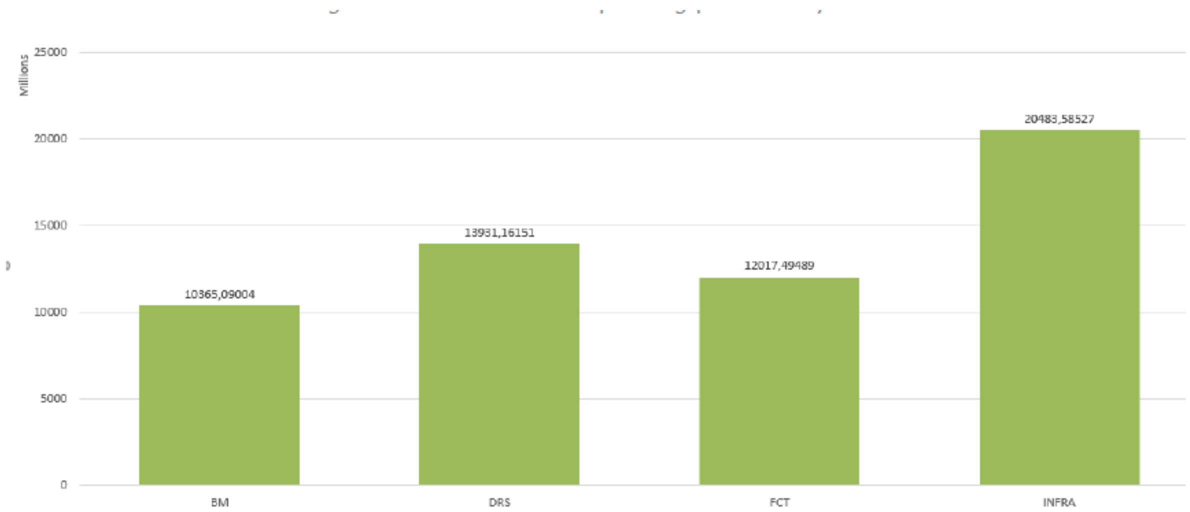


Figure 1: Money (€) spent for the procurement of technologies related to the four basic research areas, Source: EU Security Market Study

In the context of the study a comprehensive taxonomy of the products and services has been developed as a first step towards a harmonised categorisation of security-related technologies. This taxonomy built on previously developed taxonomies from various organisations. Over 550 products are included in the repository, each corresponding to one of the four main research areas and to a specific functional area (European Commission DG HOME, 2022).

The study produced significant results, with the future market analysis from both the supply and demand sides being one of the most crucial. The EU market is expected to become more fragmented, as Member States demand products which are tailored to their individual needs. Especially in the FCT and DRS research areas, funds are mainly national, thus products cover the needs and challenges faced internally. Moreover, the often-observed lack of harmonisation and standardisation leads to the duplication of existing technologies with the re-development of similar products exceeding synergies among developers and suppliers. Furthermore, capability-driven approaches for the development of products which address end user requirements are missing. A characteristic example could be the investment in surveillance systems (especially regarding the FCT area), whereas digital security products, that are identified as crucial by the end users, present much lower numbers. This lack of capability-driven approaches is expected to widen the gap between end users and providers.

It becomes apparent that a capability-driven approach is the first step in order to link end user requirements with the providers' interests. It could provide an efficient way to address capability gaps and functionalities that are required by safety and security practitioners and are still missing or require further development. Therefore, a harmonised and holistic approximation could be achieved and the linkages between the two ends of the market, the demand and the supply, could be strengthened.

End users' requirements identification was one of the core objectives of the H2020 FIRE-IN project. FIRE-IN, was a networking project which brought together stakeholders from different domains i.e., technological providers, first responders, researchers, policy makers and standardisation experts. The aim of the project was to provide a well-documented matrix of capability challenges expressed by first responders in workshops which took place during three iterations of the project (FIRE-IN, n.d.). Figure 2 presents the capability challenges matrix, which consists of seven capabilities, depicted in the first column of the matrix, and four main scenarios faced by first responders during operations, depicted in the first row. Each of the 27 challenges is assigned to a specific capability and scenario.

	High Flow of effort in hostile environment	Low frequency, high impact events	Multi-agency/multi-leadership environment	High level of uncertainty
Incident Command Organization	Focus on sustainability of safe operations	Prioritize the reduction of vulnerability and increase interactions with the public. **Sendai 7, 19, 33**	Distribute decision-making	Strategies choosing safe scenarios, and maintaining credibility
Pre-planning	Pre-plan a time efficient, safe response. **Sendai 6, 8, 19, 24, 27, 33, 34**	Negotiate solutions with stakeholders for anticipated scenarios. **Sendai 6, 7, 19, 24, 27, 33**	Plan interoperability and enhance synergies. **Sendai 8, 19, 34**	Focus on governance and capacity building towards more resilient societies. **Sendai 7, 24, 33**
Guidance instruments	Establish procedures and guides. **Sendai 34**	Standardize capabilities in front of pre-established scenarios. **Sendai 34**	Establish an interagency framework. **Sendai 8, 19, 34**	Build doctrine for resilience in emergency services and societies.
Knowledge Cycle	Train specific roles	Learn about possible scenarios focusing efforts in key risks and opportunities. **Sendai 24.**	Build a shared understanding of emergency and train interagency scenarios. **Sendai 8, 19, 24, 33, 34.**	Focus on integral risk management. Sendai 33
Information management	Information cycle. **Sendai 24 IFAFRI 4**	Manage key information focused on decision-making **IFAFRI 4**	Define common information management processes between agencies. **Sendai 19, 24**	Provide an efficient, flexible flow of information for a shared understanding
Community Involvement	Develop public self-protection to minimize responders exposures **Sendai 27, 33**	Prepare population for the worst scenario before it happens. **Sendai 7, 24, 25, 33**		Cultural changes in risk tolerance and resilience **Sendai 7, 19, 24, 33**
Technology	Use technology to assess risks and minimize responder's engagement **IFAFRI 1, 2, 3**	Simulate complex scenarios **IFAFRI 4**	Technological tools to support data sharing	Get a clear picture of the risk evolution **IFAFRI 1**

Figure 2: FIRE-IN matrix and the 27 Capability Challenges, Source: FIRE-IN D3.3 *(The Consortium of the FIRE-IN Project, 2020)*

The level of coverage of each challenge was assessed based on solutions which address these gaps. Technological systems and tools, standards, best practices, widely adopted operational protocols and also the outcomes of national, EU and international research projects are considered as tools. A wide desktop research as well as communications with suppliers took place throughout the implementation of the project with the aim to see the extent to which each of the 27 capability challenges is covered by the aforementioned solutions. Interactions between suppliers and end users were increased through online surveys and workshops, during the third iteration of the project.

A questionnaire was developed under the framework of the project targeting first responders with the aim of depicting the extent to which technology meets their needs and increases their operational capacity (The Consortium of the FIRE-IN Project, 2022). One of the most significant outcomes was that, although technologies have greatly facilitated the work undertaken by first responders' agencies, some further advancements are expected, mainly in resilient communications, command-and-control systems, GIS apps and geolocation technologies, risk assessment systems and AR/VR simulation software. The following figure presents the values of first responders' answers regarding the types of technologies, for which they expect further improvements and advancements.

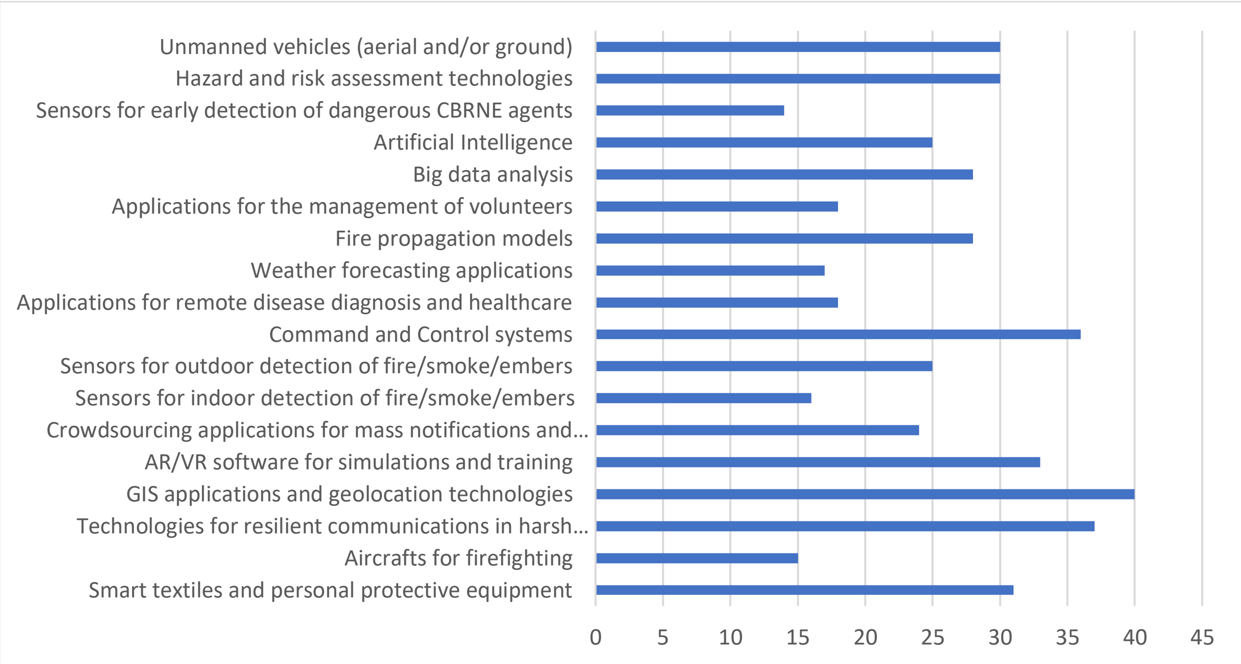
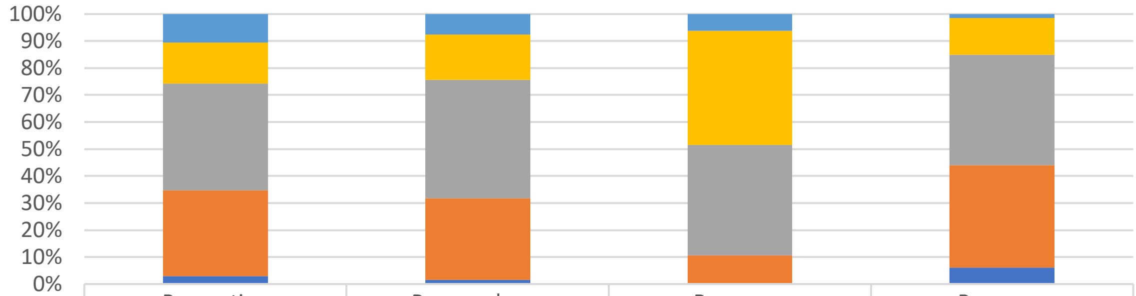


Figure 3: Technologies, for which first responders expect further development, Source: FIRE-IN D3.4 *(The Consortium of the FIRE-IN Project, 2022)*

Moreover, it was deduced that although all four phases of disaster management i.e., prevention, preparedness, response and recovery, are addressed by technological innovations, the level of coverage differs, with response being the most addressed and recovery the least. Furthermore, prevention and preparedness presented relatively low numbers, in comparison to response (The Consortium of the FIRE-IN Project, 2022). The following figure clearly depicts the above statement.



	Prevention	Preparedness	Response	Recovery
Very much	10.60%	7.60%	6.10%	1.50%
Much	15.20%	16.70%	42.40%	13.60%
Quite	39.40%	43.90%	40.90%	40.90%
A little	31.80%	30.30%	10.60%	37.90%
Not at all	3%	1.50%	0%	6.10%

Not at all A little Quite Much Very much

Figure 4: The extent to which technology addresses the four disaster management phases, Source: FIRE-IN D3.4

In addition to the questionnaire a joint event was organised in early 2022, between FIRE-IN and MEDEA as both projects share many common topics. With the participation of technological providers and practitioners, networking as well as cooperation was boosted, as on one hand providers had the opportunity to be informed regarding end users' needs, while on the other first responders had the chance to see what types of technologies are considered as interesting developments for the short-, mid- and long-term future. An important outcome of the discussion was the highlighting of the technologies that were simultaneously considered as essential by end users and of great interest for further developments by the technological domain. Among the variety of systems, early warning technologies, unmanned vehicles, command-and-control systems, AI, AR/VR simulations, resilient communications, GIS and geolocation applications and big data analysis systems stood out (The Consortium of the FIRE-IN Project, 2022). The following figure depicts the most important technologies for technological providers and practitioners for the mid- to long-term future.

Figure 5: Important technologies for the future according to practitioners and technology providers, Source: FIRE-IN D3.4

Following the recommendations of the DG HOME study as well as the results of networking projects with a significant impact on the disaster management community, the PANTHEON project aims to deliver technologies, that will greatly facilitate stakeholders, who play an important role in the management of crises, which, as already mentioned, are becoming increasingly complicated with cascading consequences that are difficult to predict. The project aims to provide a technological system building upon the experience and expertise of the technical partners of the Consortium as well as upon the capabilities and opportunities that the use of state-of-the-art systems and tools offers. Several technologies will be exploited such as space-based earth observation systems, climate modelling based on AI techniques, observation systems, either in-situ or from aerial vehicles, early warning systems for smart cities for floods, earthquakes and wildfires, data sharing technologies and risk identification and mitigation models for critical infrastructure. This deliverable includes those technologies that are expected to be improved and further developed throughout the lifetime of the project in comparison to their initial state and functionality, including smart city digital twins, AI-based models, DSS systems and assets management and risk monitoring systems. The following subchapters provide, inter alia, an overview of the functionalities and areas of application of these technologies as well as the improvements and advancements expected to take place during the implementation of PANTHEON.

2.1 SMART CITY DIGITAL TWIN TECHNOLOGIES

A **Digital Twin** refers to a virtual representation of a physical object, system, or process, created by integrating real-time data from sensors, historical data, and simulation models (Deren, 2021). It is a mirror image of the physical entity and enables the monitoring, analysis, and optimisation of its behaviour and performance. The concept of Digital Twins originated from the manufacturing industry but has since expanded into various domains, including Smart Cities.

A **Smart City** is a city that utilises information and communication technologies (ICT) and innovative solutions to improve the quality of life for its residents, enhance urban services, and address urban challenges effectively (Deng, 2021). It involves the integration of digital technologies, data analytics, and Internet of Things (IoT) devices to manage city infrastructure, resources, and services efficiently. The goal of a Smart City is to enhance sustainability, resilience and citizens' well-being while promoting economic development.

A **Smart City Digital Twin** (SCDT) is an advanced application of the Digital Twin concept to model and simulate the entire urban environment of a Smart City (Deren, 2021). It encompasses not only physical assets like buildings and infrastructure but also includes social and environmental aspects, such as citizen behaviour, air quality and traffic patterns. By combining real-time data, historical data and advanced simulation techniques, a SCDT enables city planners and policy makers to make data-driven decisions for urban planning, management and service optimisation. It plays a crucial role in revolutionising urban governance and transforming cities into more efficient and sustainable environments.

2.1.1 KEY CHARACTERISTICS

According to Deng et al. (2021) and Deren et al. (2021) key characteristics of Smart City Digital Twins include:

- **Bidirectional Mapping**: SCDTs enable bidirectional mapping between the physical and virtual dimensions of a city, integrating physical models, real-time sensor data, historical data and simulation techniques. This feature allows for accurate representation and interaction between the real-world environment and its digital counterpart.

- **Accurate Mapping**: SCDTs focus on accurate mapping of the city's physical assets, infrastructure and urban environment. This characteristic ensures that virtual representation mirrors the real-world city as closely as possible, enabling effective planning and decision-making.
- **Virtual-Real Interaction:** A key feature of SCDTs is their ability to facilitate virtual-real interaction, where actions and decisions made in the virtual environment can have real-world implications and vice versa. This interaction supports various urban management and optimisation processes.
- **Software Definition:** SCDTs rely on software-defined models and simulations, enhancing their flexibility and adaptability to different urban scenarios. Software definition allows for swift updates and adjustments to reflect real-world changes in the city.
- **Intelligent Feedback:** SCDTs integrate AI and machine learning algorithms to provide intelligent feedback and insights based on data analysis and simulation. This feature assists urban planners and decision-makers in making informed choices.
- **Complexity Management:** SCDTs handle the complexity of urban systems, incorporating multiple data sources and analytical tools to manage and optimise urban processes efficiently.
- **Sustainable Decision-Making**: SCDTs aid in making sustainable decisions for urban planning and development, addressing challenges such as climate change, population growth and resource depletion.
- **Urban Governance Transformation**: Implementation of SCDTs can lead to transformative changes in urban governance, promoting data-driven decision-making and citizen-centric services.

These characteristics demonstrate the potential of SCDTs to revolutionise urban planning, management and services by harnessing the power of digital technologies, data analytics, and AI to create more efficient, sustainable and citizen-friendly cities.

2.1.2 ARCHITECTURE & CONCEPTUAL MODEL

In the past, several researchers have proposed reference architectures and conceptual models for SCDTs. For instance, in a systematic review , the authors propose that SCDTs compose of several layered components as shown in the Figure 6 (Deng, 2021).

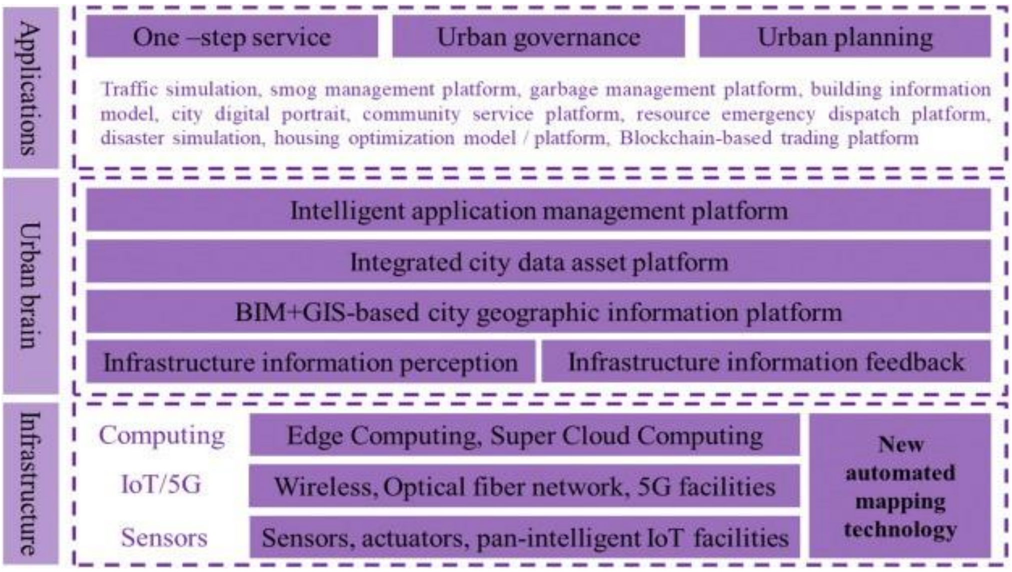


Figure 6: Composition of SCDT, Source: Deng et al., 2021

In this layered approach, the Digital Twin assumes the role of a city brain platform, which serves as the intelligence hub for the operation of smart cities. This platform includes various components such as the

Building Information Models (BIM) and the GIS-based platform, integrated city data asset platform, intelligent application management platform and infrastructure information perception and feedback platform. The city geographic information platform integrates real-world city data into a digital platform, forming the foundation for Smart City Digital Twins. The integrated city data asset platform combines administrative data and sensor-collected basic data, providing a crucial foundation for smart urban governance. The infrastructure information perception and feedback platform play a key role in connecting digital and physical cities with commercial 5G infrastructure facilitating collaborative innovation and data synchronisation. The intelligent application management platform utilises AI, big data and IoT technologies to enable data-driven decision-making, operations optimisation and simulation capabilities. Furthermore, the emerging application layer leverages City Information Models (CIMs) and city data to offer scenario services, data services, and simulation services. Scenario services provide real-time data on urban architecture, geo-space and environments, while data services track past, current and predict future behaviours of physical entities. Simulation services simulate time, events, and scenarios, supporting decision-making through pre-planning designs.

From the disaster management perspective, Ford & Wolf (2020) have proposed a conceptual model for SCDT systems to effectively support community disaster management, as shown in Figure 7 (Ford, 2020).

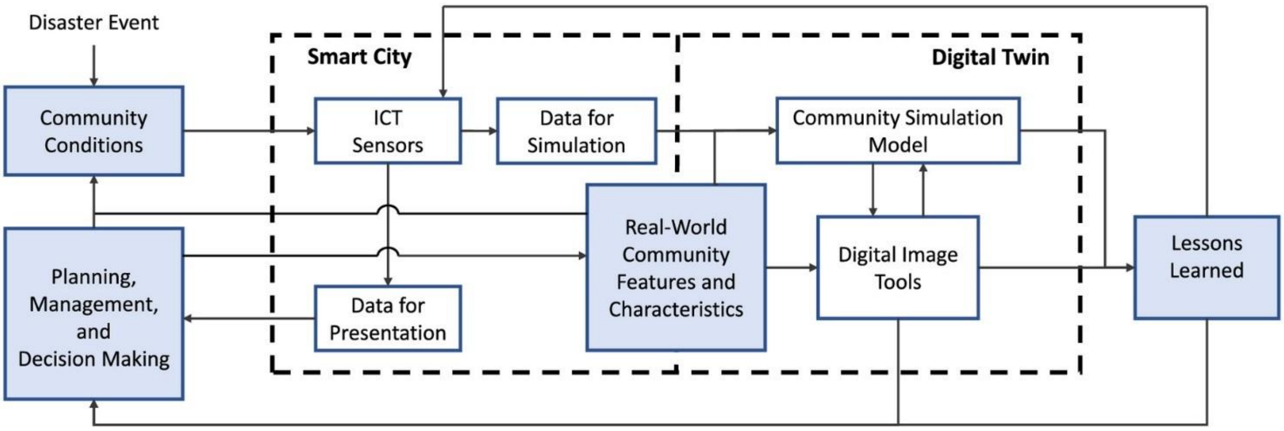


Figure 7: Community disaster management model with a SCDT, Source: Ford & Wolf, 2020

The model illustrates the minimum combination of components and information flows required for disaster management with continuous SCDT monitoring of community conditions. It highlights the iterative nature of disaster management with the SCDT continuously monitoring the impacts of decisions and actions and reflecting them in the digital twin. The model composes of three principal parts: (i) components outside the SCDT but impacted directly or through lessons learnt, (ii) smart city components and (iii) digital twin components. The components outside the SCDT connect it to the community and the disaster event, including community conditions, features and characteristics, as well as lessons learnt from simulations and digital image tools. Smart city components consist of sensors providing real-time data for decision-making and presentation to community members. Digital twin components include tools generating digital images of the community and simulation models to predict future conditions. The information loops within the model enable iterative data-driven decision-making during disaster management. SCDT significantly improves the speed and effectiveness of disaster management processes by providing real-time data, forecasting, and monitoring impacts in a way that humans cannot achieve manually. This SCDT model holds potential for improving disaster management strategies, enhancing community resilience, and supporting decision-makers in effectively responding to disasters. Implementing SCDT requires addressing challenges such as integrating diverse community infrastructures and securing adequate technology and funding support.

2.1.3 FIELD APPLICATIONS

Smart City Digital Twins have been promoted as a solution in several application domains, which are presented below:

1. Urban planning & Energy management

Several researchers have proposed the use of a SCDT for urban planning and energy management. Xia et al. (2022) provided a review and bibliometric analysis of the integration of GIS and BIM in city digital twin technology. The study identified 131 unique articles for co-citation analysis (using CiteSpace) after applying inclusion and exclusion criteria and removing duplicates. The authors used content analysis and bibliometric analysis to assess the existing literature. The study found that while the research domain is quite new, the publication rate has grown significantly in recent years. The article also highlights the importance of two-directional interactions in digital twins and the interoperability requirements of various software. The study provides insights into the progress, hotspots and trends of using BIM to reduce building energy consumption (Xia, 2022).

Deng et al. (2021) investigated the use of a SCDT for various purposes such as urban planning, infrastructure management, and policy development. The study provides a systematic review of the literature on digital twin cities, examining the current state of research and identifying key themes and trends. The review found that digital twin cities have the potential to revolutionise urban governance by providing a platform for data-driven decision-making. The use of digital twin technology can help cities to optimise their resources, improve their services and enhance their resilience. The article also discusses the challenges associated with implementing digital twin cities, such as data privacy concerns, technical limitations, and the need for interdisciplinary collaboration. In conclusion, the article suggests that digital twin cities have the potential to become a new pattern of urban governance for smart cities. However, further research is needed to explore the full potential of this technology and to address the challenges associated with its implementation (Deng, 2021).

White et al. (2021) discussed the concept of a SCDT and its role in citizen feedback. It highlights that an accurate 3D model of a city can be published online, allowing the public to view proposed changes in urban planning and policy. This open and public model enables citizens to interact and provide feedback on planned changes in the city. The use of digital twins in smart cities is becoming increasingly popular, with over 500 cities expected to deploy digital twins by 2025. Digital twins enable the planning, management and optimisation of cities across various applications, including mobility and sustainability (White, 2021).

Ruohomaki et al. (2018) examines digital twins from the energy management perspective and highlighted that the utilisation of visual 3D models in smart cities could provide a rich source of information related to urban planning and energy management. The models can be used to compare the energy consumption between similar buildings or to display the potential solar panels in a certain district. Application of this kind of models and linking the sensor data with a CityGML data model of Helsinki evolved into interoperable semantic data models, effectively turning a visualisation tool into a data platform that can include any type of data related to smart city. The models have soon become elemental in not only managing a smart city but also as a platform for co-design and development together with the citizens (Ruohomaki, 2018).

2. Disaster & Incident Management

Besides urban planning and energy management, the SCDT concept has been utilised in other applications, such as disaster and incident management. Regarding disaster management, relevant work by Ford & Wolf (2020) proposed a conceptual model of SCDT for disaster management and highlights the importance of information loops and addressing threats to SCDT development. The text emphasises on the interdependencies among community systems and the need for interventions that influence both systems and populations. The phases of community disaster management are outlined and the potential benefits of SCDT are discussed. Digital twins accurately forecast future conditions, enabling effective decision-making. SCDT development for disaster management offers valuable benefits and serves as a testbed. The model illustrates key components and information flows of a SCDT. Integration risk and fatigue risk are challenges to SCDT development. Public ownership and stakeholder involvement are also important. The Flood Alert System 4 (FAS) in Houston demonstrates the potential of SCDTs in disaster management. Future research opportunities include social infrastructures and forecasting quality. The text concludes by mentioning the iterative nature of disaster management and the need for further development of SCDT at the community level (Ford, 2020).

Focusing on disaster management Mohammadi & Taylor (2021) explored the significance of SCDTs in disaster decision-making and highlighted how Smart City Digital Twins aid in capturing and predicting city dynamics accurately, particularly in the face of various stressors like heat waves, hurricanes, and epidemics (Mohammadi, 2021). The vulnerability of cities to disasters in terms of mortality and economic loss necessitates effective data-driven decision-making by local governments, leveraging data, technology, and computational capabilities. To enhance resilience, the research emphasises robustly capturing urban system dynamics through recurrent sensing and infrastructure modelling, considering human activities and interactions. However, the computational approaches used in SCDTs must be agile enough to match the pace of changes in urban systems for optimal results. SCDTs provide a promising approach to improve preparation, recovery, and ongoing disaster scenarios by enabling local governments to make data-driven decisions in real-time, effectively managing risks and enhancing the resilience of the city.

For incident management, relevant work explores the significance of digital twins in modelling and monitoring cities and systems, considering their varying terminologies and maturity levels across different sectors (Wolf, 2022). The study specifically focuses on developing a process digital twin to enhance incident management in smart cities, emphasising on data integration, stakeholder collaboration and real-time monitoring for effective incident response. The prototype incident response system utilises cloud computing and Azure Maps to simulate and visualise incidents, responders' locations, traffic and weather data. Using a system engineering approach, the research analyses stakeholders' current challenges to formulate future system requirements. The goal is to address challenges related to data utilisation, heterogeneity and communication inefficiencies that arise when dealing with diverse datasets generated by IoT devices. The Microsoft Azure-based prototype provides analytical functionalities, automatic updates and real-time weather and traffic data to support emergency service coordination. The study aims to lay the foundation for a data ontology that can support multi-agency incident response in future smart cities. The development of this digital twin for incident management seeks to improve incident response and decision-making processes in urban environments, making them more resilient and responsive to emergencies and disasters. The paper includes figures depicting various steps of the incident process in a SCDT. These figures showcase the utilisation of Microsoft Azure cloud computing and web technologies to support stakeholders in incident response and decision-making.

3. Community Engagement & Social Planning

Apart from the previous applications, SCDTs have been proposed for community engagement and social planning. Abdeen & Sepasgozar (2022), proposed the implementation of a SCDT to foster community involvement in smart city infrastructure planning. The SCDT architecture comprises of five layers: data acquisition (utilising OpenStreetMap, Sydney 3D city model, DEM, and VGI), data transmission (via Wi-Fi), digital modeling and data complementarity (using BIM/CIM and agent-based models), data/model integration (integrating 3D city information and community feedback simulations using deep learning algorithms) and application (visualising community expectations, safety concerns, and environmental issues) (Abdeen, 2022). By empowering the public and engaging urban planners, policy makers and developers, the SCDT aims to facilitate informed decision-making during the planning and construction stages. The study emphasises community input and enhancement in future phases, thus envisioning a collaborative approach towards sustainable and participatory territorial management. The proposed SCDT seeks to bridge the gap between the public and decision-makers, promoting a more inclusive and transparent process for shaping smart cities.

Regarding social planning, another study discusses the concept of the Urban Digital Twin (UDT) in the context of Smart Cities and urban innovation (Yossef Ravid, 2023). While the UDT is a data-driven 3D city modeling tool that focuses on the physical dimensions of cities, there is a call for a "social turn" in the field of Smart Cities to create a Social Urban Digital Twin (SUDT) that represents both the physical and social environments. Building SUDTs requires interdisciplinary knowledge from sociology, anthropology, planning and ethics studies. The article presents a six-phase protocol for developing SUDTs and demonstrates it through a case study on the experience of elderly residents in Haifa during the COVID-19 pandemic. The SUDT has the potential to contribute to urbanism theory and its methodological aspects, aiming to integrate technological conceptions and social-theoretical content. The article also discusses the contributions and limitations of the SUDT in Smart City initiatives. It provides a comprehensive list of academic articles related to various topics in Smart Cities and urban planning, showcasing the authors' expertise and research interests in urban planning and social considerations. Overall, the study emphasises the importance of incorporating social aspects into Smart City decision-making and urban management, enhancing smart city planning with a social turn.

4. Case Studies

Concerning practical application of the SCDT models, several cities have been utilised for showcasing the applicability of such models in real-world pilots. A study by Dembski et al. (2020) explores the development of an urban digital twin prototype in Herrenberg, Germany, for smart and sustainable urban planning (Dembski, 2020). The twin integrates 3D city models, simulations and social data from citizens, fostering stakeholder collaboration and participatory processes. Virtual reality technology aids in the participatory processes, emphasising on the connection between urban digital twins and smart cities. The urban digital twin received positive feedback, holding significant potential for improving communication and decision-making in urban development. The study highlights the importance of people-centred innovations and data sovereignty, particularly for smaller communities. It further highlights the significance of open data and people-centred approaches in the context of smart cities. The prototype urban digital twin, known as COVISE, enables collaborative visualisation and simulations, enhancing spatial planning and aiding city design. The case study on Herrenberg showcases how the urban digital twin has positively impacted mobility and inclusivity in the city. The article also addresses the need for further research to test the twin's effectiveness in real-life conditions and its potential to contribute to sustainable urban energy systems. The text contains valuable insights into the application of urban digital twins in smart city initiatives, digital participation in urban contexts and their potential contributions to enhancing urban well-being and spatial planning.

Another study by explores the implementation of a data-driven digital twin in Ålesund, Norway, to facilitate sustainable decision-making in smart cities (Major, 2021). The primary objective is to utilise big data and citizen engagement to support informed and sustainable urban planning. The study addresses two key barriers to effective citizen engagement in smart city initiatives. The first barrier is related to data privacy, which may hinder citizens from actively participating in data-sharing processes. The second barrier involves the complexity of big data, which may be challenging for non-experts to comprehend and utilise effectively. The research focuses on utilising a data-driven digital twin, a virtual representation of the physical city that incorporates real-time data from various sources. By harnessing this technology, urban planners and policy makers can gain valuable insights into urban dynamics and citizen behaviours, enabling them to make data-driven decisions for urban development.

2.1.4 GAP IDENTIFICATION AND PANTHEON CONTRIBUTION

The Pantheon project aims to support Community-Based Disaster Risk Management (CBDRM) operations by using cutting-edge technologies such as SCDTs, decision support systems, AI, UAV & satellite imagery as well as in-situ sensors. To this end, the current literature leaves research space on SCDTs for disaster risk management that the PANTHEON consortium can leverage, for several reasons.

A large body of the contemporary literature is focused on urban planning and energy management, while the primary focus of Pantheon SCDT is disaster management (Deng, 2021), (Deren, 2021), (Francisco, 2020), (Huang, 2022).

The studies that focus on disaster & incident management do not provide sufficient details on the implementation (e.g., defining in detail the data model to be used, the considered community characteristics, the use of forecasting technologies and simulation models) of such a SCDT i.e., they work mostly on the concept-level, and do not present in detail the use of community engagement and multi-source data, such as satellite, UAV and in-situ, as PANTHEON does (Fan, 2021), (Ford, 2020), (Mohammadi, 2021), (Wolf, 2022).

The studies focusing on community engagement and social planning do not present in a highly detailed manner how the envisioned SCDTs could be utilised in the field of disaster management, a core element of the PANTHEON project (Abdeen, 2022), (White, 2021), (Yossef Ravid, 2023).

Finally, the case studies provided in the literature do not consider the pilot areas and disasters that have been defined in Pantheon (Dembski, 2020), (Ford, 2020), (Major, 2021), (Ruohomaki, 2018). More information regarding the pilot areas of Pantheon are included in D2.1 “Community based DRM analysis and Regional Ecosystem” (The Consortium of the PANTHEON Project, 2023) and D2.2 “Multi-Hazards/risk data and assessment report” (The Consortium of the PANTHEON Project, 2023).

2.2 AI-BASED MODELLING AND SELF-ADAPTIVE SIMULATIONS

AI-based modelling refers to the use of AI techniques and algorithms to build and develop models that can make predictions, generate outputs, or perform specific tasks. The models are typically built using Machine Learning (ML) and Deep Learning (DL) techniques, which are subsets of AI. Along with speech and recognition, these technologies can be included in the smart city AI technologies (H.M.K.K.M.B. Herath, 2022).

ML Models are trained on historical data to recognise patterns about individuals, business processes, transactions and events and make predictions or decisions. Popular ML algorithms include decision trees, random forests, support vector machines and logistic regression.

AI, particularly ML, has grown rapidly in recent years in the context of data analysis and computing that typically allows the applications to function in an intelligent manner. ML usually provides systems with the ability to learn and enhance from experience automatically without being specifically programmed and is generally referred to as the most popular latest technologies in the fourth industrial revolution (4IR or Industry 4.0). "Industry 4.0" is typically the ongoing automation of conventional manufacturing and industrial practices, including exploratory data processing, using new smart technologies (Sarker, 2021).

ML methods have been contributing to various application domains with promising results in e.g., mobility management and monitoring, city planning, resource allocation, energy demand and consumption prediction, food supply and production prediction, air pollution monitoring and prediction, among others. For instance, applied artificial neural networks (ANNs) have many applications in smart cities, including hazard detection, water supply, energy and urban transport. Another ML method which has been applied to solve problems of different aspects of smart cities is decision trees. Researchers have applied DTs to address the issues related to businesses, air pollution, urban transport and food to develop a smart city (Saeed Nosratabadi, 2010).

Deep learning models are a subset of ML that use ANNs to process and learn from data. They are especially powerful for tasks involving image recognition, natural language processing and speech recognition. Popular DL architectures include convolutional neural networks (CNNs) and recurrent neural networks (RNNs).

Following the evolution of big data collection, storage and manipulation techniques, DL has drawn the attention of numerous recent studies proposing solutions for smart cities. These solutions were focusing especially on energy consumption, pollution levels, public services and traffic management issues. Predicting urban evolution and planning is another recent concern for smart cities that benefits from the use of deep learning algorithms (Alghamdi, 2023).

Natural Language Processing (NLP) models are specifically designed to understand and process human language. They can be used for tasks like sentiment analysis, language translation, chatbots and text summarisation. Real-life applications including information retrieval, information extraction, machine translation, text simplification, sentiment analysis and text summarisation NLP comprise the main part of research at present. Textual software such as MS-word and word-processor is an important NLP consideration for automated grammar and spelling check improvement. Office 365 is the best example, which provides both text as well as dictates features, that actually are the best NLP applications. IoT brought modern trends to communicate and translate language to language version of context. It provides ease of communication for language learners, researchers and tourists to communicate in new places. Several IoT devices are introduced in the market to share and communicate. IoT made easy to bring smart devices as a smart language translator without having human assistance (Irum Hafeez Sodhar, 2020).

Generative Models are capable of generating new data similar to the data they were trained on. Deep generative models (DGM) are neural networks with many hidden layers trained to approximate complicated, high-dimensional probability distributions using a large number of samples. When trained successfully, the DGMs can be used to estimate the likelihood of each observation and to create new samples from the underlying distribution. Developing DGMs has become one of the hottest research fields in AI in recent years. The literature on DGMs has become vast and is growing rapidly. Some advances have even reached the public sphere, for instance the recent successes in generating realistic-looking images, voices, or movies, the so-called deep fakes. Despite these successes, several mathematical and practical issues limit the broader use of DGMs: given a specific dataset, it remains challenging to design and train a DGM and even more challenging to find out why a particular model is or is not effective (Lars Ruthotto, 2021).

Reinforcement learning is a type of ML, where an agent learns to take actions in an environment to maximise a reward signal. It is commonly used in scenarios such as game playing, robotics and optimisation problems like boosting communications. Smart city communication networks hold the promise of harnessing the IoT, smart devices, intelligent energy grids, autonomous cars and many other data architectures to improve the quality of life for every citizen. As time and progress have gradually shifted this concept from an idea into a reality, the possibilities for what services a smart city might provide have greatly increased. Along with that expansion, the number of devices that may need to be supported across a communications network has multiplied enormously. However, existing congestion control protocols are not equipped to support this higher requirement for network performance. New protocols are needed to provide higher data throughput, reduce queuing delays and packet loss and maintain stable and reliable communications pathways. The end-to-end congestion control protocol presented in this article does all these things. Called high throughput congestion control (HTCC), the framework takes full advantage of reinforcement learning and a fast growth algorithm to adaptively control the bytes in flight across the links of the network to suit the prevailing network conditions. The result is a protocol that not only finds the optimal trade-off between throughput, latency and packet loss, but also significantly speeds up the learning process to avoid wasting network resources, use all free bandwidth and maximise network utilisation.

A comprehensive set of experiments with HTCC and six state-of-the-art protocols i.e., Copa, PCC Vivace, PCC-Allegro, TCP Cubic, TaoVA-100x, and FillP-Sheep- demonstrate that, in most conditions, HTCC can make the best trade-off between throughput, delay, and loss rate (Zhenchang Xia, 2021).

2.2.1 FIELD APPLICATIONS

AI-based modelling can be used in various industries and applications, such as healthcare for medical diagnosis, finance for fraud detection, autonomous vehicles for navigation and entertainment for recommendation systems. The success of these models heavily relies on the availability of large and high-quality datasets, computational power, and skilled data scientists and AI engineers to design, train, and fine-tune the models. AI plays a crucial role in various domains of a smart city, enabling more efficient and sustainable urban environments (H.M.K.K.M.B. Herath, 2022):

1. Transportation and mobility:
    - Intelligent Traffic Management: AI can analyse real-time traffic data from various sources, such as cameras and sensors, to optimise traffic flow and reduce congestion.
    - Autonomous Vehicles: Self-driving cars and autonomous public transportation systems use AI to navigate safely and efficiently through city streets.
    - Ridesharing and Routing: AI algorithms can optimise ride-sharing services and suggest the most efficient routes for commuters, reducing travel time and emissions.
2. Energy management:
    - Smart Grids: AI helps in managing energy distribution and consumption in real-time, optimising energy usage and reducing wastage.
    - Demand Response: AI can predict and adjust energy demand based on patterns and needs, ensuring a balanced energy grid.
    - Energy Efficiency: AI-powered systems can monitor and control energy usage in buildings and public spaces, leading to greater energy efficiency.
3. Urban planning:
    - Data Analytics: AI can analyse vast amounts of data from various sources, including satellite imagery and sensor networks, to provide valuable insights for urban planning and development.
    - Land Use Optimisation: AI algorithms can help determine the best use of land and resources, considering factors like population density, transportation, and infrastructure requirements.

4. Public safety:
    - Predictive Policing: AI can analyse crime data and patterns to predict and prevent criminal activities, enhancing public safety.
    - Video Surveillance: AI-powered cameras can identify and alert authorities about potential security threats or unusual activities in public areas.
5. Healthcare and public services:
    - AI in Healthcare: Smart cities may use AI to enhance healthcare services, such as remote patient monitoring and personalised medical assistance.
    - Chatbots and Virtual Assistants: AI-powered chatbots can provide residents with real-time information about city services, events, and emergency updates.
6. Waste management:
    - Smart Bins: AI-enabled waste bins can optimise waste collection routes and schedules, reducing costs and promoting cleanliness in the city.
    - Recycling and Sorting: AI can aid in automating recycling processes, improving the efficiency of waste separation and management.
7. Environmental monitoring:
    - Air Quality Management: AI systems can monitor air quality levels and identify pollution sources, enabling timely interventions to improve air quality.
    - Water Management: AI can analyse data from sensors to manage water resources, detect leaks, and optimise water distribution.
8. Citizen engagement:
    - AI-driven platforms can collect and analyse citizen feedback and preferences to shape city policies and improve service delivery.
    - Social Media Analysis: AI can monitor social media platforms to gauge public sentiment and identify emerging issues or concerns.

By leveraging AI in these domains, smart cities aim to enhance quality of life, optimise resource utilisation and create more sustainable and resilient urban environments for their residents. However, it's crucial to address privacy, security and ethical concerns to ensure the responsible and beneficial deployment of AI in smart cities.

2.2.2 SELF-ADAPTIVE SYSTEMS

Self-adaptive systems can modify their runtime behaviour in order to achieve system objectives. Unpredictable circumstances such as changes in the environment of the system, system faults, new requirements and changes in the priority of requirements are some of the reasons for triggering adaptation actions in a self-adaptive system. To deal with these uncertainties, a self-adaptive system continuously monitors itself, gathers data and analyses them to decide if adaption is required. The challenging aspect of designing and implementing a self-adaptive system is that not only must the system apply changes at runtime, but also fulfil the system requirements to reach a satisfying level. Engineering such systems is often difficult as the available knowledge at design time is not adequate to anticipate all the runtime conditions (S. Mahdavi-Hezavehi, 2017).

As stated before, Smart Cities combine advances in Internet of Things, big data, social networks, and cloud computing technologies with the demand for cyber–physical applications in areas of public interest, such as health, public safety and mobility. The end goal is to leverage the use of city resources to improve the quality of life of its citizens. Achieving this goal, however, requires advanced support for the development and operation of applications in a complex and dynamic environment. Middleware platforms can provide an integrated infrastructure that enables solutions for smart cities by combining heterogeneous city devices and providing unified, high-level facilities for the development of applications and services. Although several smart city platforms have been proposed in the literature, there are still open research and development challenges related to their scalability, maintainability, interoperability, and reuse in the context of different cities, to name a few. Moreover, many of the available platforms lack extensive scientific validation, which hinders a comparative analysis of their applicability. Aiming to close this gap is InterSCity, a microservices-based, open-source, smart city platform that enables the collaborative development of large-scale systems, applications and services for the cities of the future, contributing to turn them into truly smart cyber–physical environments. The architecture of the InterSCity platform demonstrates that the platform can scale horizontally to handle the highly dynamic demands of a large smart city while maintaining low response times (Arthur de M. Del Esposte, 2019).

2.2.3 GAP IDENTIFICATION AND PANTHEON CONTRIBUTION

As the landscape of AI in smart cities is continuously evolving, there are still several gaps and challenges that need to be addressed to fully realise the potential of AI in smart city development. Addressing these needs requires permanent collaboration between governments, technology providers, researchers, and citizens.

In the context of the PANTHEON project, there are some spiking gaps that bring multiple shortcomings in the development of a community-based DRM system:

- Data Privacy and Security**:** Smart cities rely heavily on data collected from various sources like sensors, cameras, and IoT devices. Ensuring the privacy and security of these data is crucial, as any breach could have severe consequences on citizen trust and system integrity.
- Interoperability and Standardisation: Different smart city systems often use proprietary technologies and protocols, making it challenging to integrate and share data seamlessly across various applications. Standardising data formats and communication protocols is necessary to enable efficient collaboration between different AI-based systems.
- Data Quality and Availability**:** The success of AI models depends on the quality and quantity of data available for training. In many cases, the data collected by smart city infrastructures may be incomplete, biased, or of low quality, which can affect the accuracy and reliability of AI-based models.
- Ethical and Fair AI Practices**:** AI models should be developed and deployed bearing in mind ethical considerations to avoid biased outcomes and discrimination against certain groups. Ensuring fairness, transparency, and accountability in AI algorithms is essential for building trustworthy smart city solutions.
- Energy Efficiency and Sustainability**:** AI algorithms often require significant computational resources, which can strain the energy consumption of smart city infrastructure. Developing energy-efficient AI models and optimising their deployment is crucial to reduce the environmental impact.
- Real-time Decision Making**:** Many smart city applications require real-time decision-making capabilities. Achieving low-latency responses while maintaining accuracy is a challenge for AI-based models, especially in complex scenarios.
- Community Engagement and User-Centric Design**:** The successful implementation of smart city initiatives depends on the acceptance and active participation of citizens. Involving communities in the design and decision-making process is essential to create solutions that truly meet their needs and preferences.
- Infrastructure and Connectivity: Some areas may lack adequate infrastructure and connectivity required for the seamless functioning of AI-based smart city applications. Addressing the digital divide and ensuring widespread access to the internet is essential for the equitable deployment of AI technologies.
- Regulatory and Policy Frameworks**:** The rapid advancement of AI technologies often surpasses the development of appropriate regulations and policies. It is essential to have a robust legal framework that governs the use of AI in smart cities to address potential risks and safeguard citizen rights.

- Scalability and Flexibility**:** As smart city infrastructures continue to grow, AI models should be scalable and flexible enough to adapt to changing requirements and accommodate the integration of new technologies.
- User Education and Training**:** Citizens, city officials, and stakeholders should be adequately educated about the benefits, risks and proper usage of AI-based smart city technologies to foster greater acceptance and collaboration.
- Economic Viability**:** Many AI-based solutions for smart cities might be costly to implement and maintain. Ensuring the economic viability and long-term sustainability of these projects is crucial for their success.

Since some of the aforementioned gaps are out of the scope of the research undergone during PHANTEON, the focus will be centred to mitigate the technologically dependent gaps.

2.3 DECISION SUPPORT SYSTEMS AND ASSETS MANAGEMENT TECHNOLOGIES

Decision Support Systems (DSS) play a vital role in modern decision-making processes, aiding decision-makers in analysing and evaluating complex, unstructured and non-repetitive tasks. They are becoming crucial for sustainable smart city development, since they integrate complex models from various domains like e-government, traffic management, logistics and smart grids. Stakeholders rely on domain experts using these models to make well-informed decisions for urban growth and citizen well-being.

2.3.1 DSS MODEL DEFINITIONS

Preliminary modern surveys for DSS define a Decision Support System as an interactive computer-based system designed to assist decision-makers instead of replacing them. It makes use of data and models to solve problems that may vary in their degree of structure, ranging from non-structured (unstructured or ill-structured) to semi-structured and structured tasks. Sprague (1980) (Sprague, 1980) and Eom and Kim (2017) (Eom S. K., A survey of decision support system applications (1995–2001), 2017) define a properly termed DSS as a list of specific characteristics:

- DSS tends to be aimed at the less well structured, underspecified problem that upper-level managers typically face.
- DSS attempts to combine the use of models or analytic techniques with traditional data access and retrieval functions.
- DSS specifically focuses on features which make them easy to use by non-computer-proficient people in an interactive mode.

The primary focus of a DSS is on enhancing the effectiveness of decision processes rather than simply improving efficiency. DSS can be broadly classified into two categories:

1. **Knowledge-based**: In knowledge-based systems, decision rules are formulated using IF-THEN statements. The system then retrieves relevant data to evaluate these rules and generate appropriate actions or outputs. These rules can be derived from various sources, such as literature-based evidence or practice-based experience.
2. **Non-knowledge based**: non-knowledge based DSS still rely on data sources but leverage technologies like AI, ML or statistical pattern recognition to make decisions instead of explicit expert knowledge (Eom S. &., 2006).

2.3.2 SYSTEM ARCHITECTURE

According to Jung et al. (2020), a DSS comprises of five main components. These components are data management, model management, user interface, knowledge management and users, collectively working to facilitate efficient decision-making (Jung, 2020).

1. The first component, data management, includes a database and a database management system (DBMS) to store and provide the necessary data for decision-making.
2. Model management, the second component, consists of a model base and a model base management system (MBMS), allowing decision-makers to develop, modify, and control the required decision models.
3. The user interface serves as the bridge between users and the system, enabling data import/export and various analytical procedures through user-friendly and easy-to-understand dialogue functions.
4. Knowledge management, the fourth component, provides decision-makers with quantitative information about complex data relationships and alternative problem-solving solutions. Additionally, it alerts decision-makers when discrepancies arise between predicted and actual results.
5. The users of a DSS are primarily managers responsible for crucial business decisions. They select appropriate models from the model base, input necessary data from the database and evaluate and analyse the available options to determine the optimal alternative.

2.3.3 RELATED WORK ON DECISION SUPPORT MODELS FOR CIVIL DISASTER MANAGEMENT

In the realm of disaster management, DSSs have proven highly valuable. For instance, Rajabifard et al. (2015) developed an intelligent disaster DSS (IDDSS) that integrated various data types, such as road, traffic, geographic, economic, and meteorological data (Rajabifard, Thompson, & Chen, 2015). This platform aided in managing road networks during floods, providing law enforcement with precise locations to establish traffic management points (TMPs) during emergencies, thereby preventing hazardous traffic situations.

Similarly, Ishak et al. (2011) designed a smart DSS for reservoir operations during heavy rainfall emergencies (Ishak, Ku-Mahamud, & Morwawi, 2011). This conceptual model assists reservoir operators in making accurate decisions on releasing reservoir water to avoid local flooding by ensuring sufficient space for the released water. AI has also been incorporated into DSSs to enhance decision-making efficiency. For instance, Dijkstra's algorithm, widely used for finding the shortest path between two points, has found applications in forest fire simulations and route planning. Akay et al. (2012) improved this algorithm using Geographic Information System (GIS) data, helping firefighters determine the fastest and safest access routes, incorporating spatial databases of road systems and land (Akay, Wing, & Sivrikaya, 2012). These systems also account for barrier systems to simulate banned roads, identifying unforeseen scenarios and suggesting secure routes for firefighters.

However, it is crucial to acknowledge that effective disaster management systems require coordination among relevant agencies to integrate data effectively. While a DSS cannot prevent all catastrophic damage, it can mitigate potential risks through early warning strategies and appropriate preparation. In the context of disaster management, the development of intelligent systems focuses on transferring expertise from human experts to computers and implementing theoretical models based on this transferred knowledge, as proposed by Turban et al. (1988) (Turban, Cameron Fisher, & Altman, 1988).

Within the scope of AI, various methods address interdependent problems. Examples include Bayesian networks, approximate reasoning (fuzzy logic) and metadata (artificial neural networks, machine learning, genetic algorithms, and swarm intelligence). Employing a hybrid approach, these methods combine fuzzy IF-

THEN rules and optimisation techniques to collect and present inaccurate information (Simões-Marques & Figueira, 2018).

In conclusion, the development of intelligent systems in disaster management focuses on transferring expertise from human experts to computers and implementing theoretical models. Modern methods include AI models and Bayesian networks to address interdependent problems, combining fuzzy IF-THEN rules and optimisation techniques. Embracing the potential of DSSs and AI, future disaster management systems can further evolve to enhance preparedness and response strategies effectively.

2.3.4 FIELD APPLICATIONS

Different approaches exist to modelling DSSs for modern decision-making and assisting users in complex and unstructured tasks. In disaster management, DSSs have proven valuable, aiding in road network management, reservoir operations during emergencies and enhancing decision-making efficiency using AI algorithms. While DSSs cannot prevent all disasters, they contribute to risk mitigation through early warning strategies in different sectors.

An essential aspect of urban city planning involves creating a suitable approach for simulating the impacts of various urban development strategies, e.g., for 2020, 2030, and 2050, on the entire building stock within a district or city. As a result, distinct urban development scenarios are employed as initial parameters to conduct building simulations for the targeted areas (Schleicher, 2016).

For example, Schleicher et al. (2016) presented a multi-sectorial DSS for disaster management where stakeholders interact with a dynamic, web-based, geo-spatial visualisation that allows them to freely explore the city as well as different evolving aspects in the context of multiple scenarios with predictions up to 2050 (Schleicher, 2016). Their approach leverages a domain-specific modelling approach that allows for multi scenario validation over a common UI. Stakeholders can not only "*explore the city as a whole, but also inspect it in varying levels of detail, from districts, over blocks, down to individual buildings*". These domains include:

- **Density Models in Urban Planning**: Density models simulate the effects of different urban development strategies for entire districts or cities. By considering parameters like construction periods and HVAC technologies, stakeholders can efficiently plan sustainable urban environments.
- **Electrical Grid Models for Power Networks**: Electrical grid models predict network reliability and utilisation, incorporating decentralised energy resources. They aid decision-making for optimised power distribution in smart cities.
- **Thermal Grid Models for District Heating**: Thermal grid models analyse existing and future district heating designs. They consider factors like thermal storage and decentralisation to ensure efficient and sustainable thermal energy distribution.
- **Spatial Modelling and Visualisation**: Spatial modelling enables stakeholders to understand complex system impacts on the city. Tools like UCSA provide a comprehensive picture of development potentials and city complexities.

These DSSs and their models facilitate sustainable smart city design by opting for a granular approach that models different domains discretely and then superimposing them on top of a geospatial model. Density, electrical, thermal grid models, and spatial modelling empower stakeholders to make informed decisions for urban development. Collaboration among stakeholders fosters innovative and supply-secure smart cities.

This approach bodes well for simulating disaster propagation, analysing cascading effects within infrastructures and allows stakeholders to extract useful information for decision support, first response modelling and procedure drafting.

2.3.5 GAP IDENTIFICATION AND PANTHEON CONTRIBUTION

The combination of previous research on time-based critical infrastructure dependency analysis with the novel DSS for a smart city introduces a cutting-edge research direction that addresses crucial gaps in critical infrastructure protection. Previous research on the field employed a graph modelling approach to understand the cascading failures between interdependent infrastructures during large-scale and cross-sectoral disruptions (Kotzanikolaou, 2011), (Stergiopoulos, 2016).

By integrating this graph modelling approach into the SCDT of PANTHEON, the new system will be able to dynamically simulate cascading failures over time, considering various dependencies and their temporal characteristics. This integration will allow the DSS component of Pantheon to capture the evolving nature of interdependencies during hazardous scenarios, providing decision-makers with a more comprehensive understanding of the potential impacts on critical infrastructures. Moreover, the Pantheon SCDT goes beyond previous research by utilising real-time spatial and environmental data and 3D simulations over such graph models, enabling dynamic hazard proactive simulation.

By combining these elements with input from sensitive groups, such as infrastructure operators and vulnerable communities, the DSS empowers stakeholders to actively participate in the risk analysis process and share their unique insights. This participatory approach enhances the accuracy and inclusivity of the risk assessment, ultimately contributing to the overall resilience and preparedness of the city.

In summary, the integration of previous graph modelling approaches with the new PANTHEON SCDT, incorporating real-time data, 3D simulations, and input from sensitive groups, represents a novel and comprehensive research direction in critical infrastructure protection and hazard proactive simulation.

2.4 RISK MONITORING SYSTEMS

Cities are considered complex systems with massive numbers of interconnected citizens, transportation, communication network, varieties of services and businesses and utilities for improving the lifestyle of urban people. Vast numbers of people are coming towards cities, and the city government is pressured to provide the minimum services required for daily life. Excess population and rapid urbanisation bring many problems, such as socio-economic, technical and organisational problems and risks to the environmental or economic sustainability of cities.

2.4.1 FIELD APPLICATIONS

In the context of a smart city, risk monitoring systems are a critical component that helps cities identify, assess and respond to potential risks and challenges. These systems leverage technology, data analytics and interconnected devices to enhance safety, resilience and efficiency in urban environments. Smart cities deploy a wide array of sensors and IoT devices across various sectors, including transportation, energy, public safety, environment, and infrastructure. These sensors collect real-time data on parameters such as traffic flow, air quality, temperature, weather conditions, energy consumption, and more. The data collected by these sensors is processed in real-time to provide a comprehensive view of the current status of the city. This real-time monitoring allows authorities to promptly detect potential risks and respond proactively. Advanced data analytics and ML algorithms analyse the data collected from various sources to identify patterns and anomalies that may indicate potential risks. For example, sudden traffic congestion in a specific area could suggest an accident or roadblock. Early warning systems automatically generate alerts and notifications when certain predefined risk thresholds are crossed. These warnings can be sent to relevant stakeholders, including city officials, emergency services, and residents, through various communication channels. The risk monitoring system can integrate with the emergency response infrastructure of the city, enabling seamless communication and coordination during crises or disasters. This integration ensures that the right personnel is informed promptly, allowing for a quicker response and mitigation of the risk.

Risk monitoring systems in smart cities are often integrated with advanced surveillance technologies such as CCTV cameras and facial recognition systems. These technologies help in improving public safety by monitoring public spaces, identifying security threats and assisting law enforcement in maintaining order. As risk monitoring systems rely heavily on data collection and communication through IoT devices, cybersecurity is of utmost importance. Robust cybersecurity measures are necessary to protect data integrity, prevent cyber-attacks, and safeguard against potential breaches (Muhammad Saad, 2018).

Smart cities must prioritise data privacy and ensure that citizens' personal information is adequately protected. Data should be anonymised and used in aggregate to preserve individuals' privacy while still providing valuable insights for risk management (Md Eshrat E., 2023).

2.4.2 GAP IDENTIFICATION AND PANTHEON CONTRIBUTION

Sustainable smart cities are confronted by technological, organisational and external risks, making their governance difficult and susceptible to manipulation. Based on a comprehensive literature review of 796 systematically retrieved articles, a multilayered technology-organisation-environment (TOE-based) risk management framework for sustainable smart city governance is proposed. A total of 56 risks are identified and grouped into TOE categories. There are 17 technological risks, including IoT networks, public internet management and user safety concerns, with a 38.7% contribution to smart city governance risks. With a 15.6% share, there are 11 organisational risks, including user data security and cloud management. There are 28 external risks with a contribution of 46.7% to the smart city governance and consist of smart city environment, governance, integration and security risks. A multilayered TOE-based risk management framework is proposed to identify and manage the risks associated with smart city governance (Fahim Ullah, 2021).

While risk monitoring systems in smart cities have made significant advancements, there are still some gaps and challenges that need to be addressed to improve their effectiveness and ensure comprehensive risk management. In the context of PANTHEON project, issues that will be addressed are presented herein:

- **Interoperability and Data Integration**: Smart cities often deploy a wide range of sensors and IoT devices from different vendors and across various departments. The lack of standardised data formats and interoperability can hinder seamless data integration and make it challenging to obtain a holistic view of potential risks.
- **Data Silos**: In many cases, data collected by different departments or agencies in a smart city remain isolated in separate databases, leading to data silos. This can limit the ability to correlate and analyse data from multiple sources, reducing the effectiveness of risk monitoring systems.
- **Lack of Standardised Risk Metrics**: The absence of standardised risk metrics and assessment frameworks makes it difficult to compare and prioritise risks consistently across the city. A common risk assessment standard would enable better decision-making and resource allocation.
- **Cybersecurity Risks**: As smart cities heavily rely on interconnected devices and networks, they become more susceptible to cybersecurity threats. A breach in the system could not only compromise data integrity but also pose significant safety risks if critical infrastructure is compromised.

- **Privacy Concerns**: The extensive use of sensors and surveillance technologies raises privacy concerns among citizens. Striking a balance between data collection for risk monitoring and preserving individual privacy is crucial for gaining public trust.
- **Limited Integration with Emergency Services**: While risk monitoring systems can identify potential hazards, their seamless integration with emergency services and first responders may still be lacking. Timely communication and coordination with relevant authorities are vital during emergencies.
- **Incomplete Coverage**: There might be areas within a smart city that lack adequate sensor coverage, leaving potential risks unnoticed in those locations. Ensuring comprehensive coverage across the entire city is essential for a robust risk monitoring system.
- **Human Error and Maintenance**: Smart city infrastructure requires regular maintenance, updates, and calibration. Neglecting these tasks can lead to inaccurate data or malfunctioning sensors, which may impact the effectiveness of risk monitoring systems.
- **Lack of Citizen Engagement**: Engaging citizens in risk monitoring initiatives can provide valuable insights and help identify risks that might not be evident from the sensor data alone. Encouraging citizen participation and feedback can enhance the overall risk monitoring process.
- **Scalability**: As smart cities continue to grow and expand, the risk monitoring systems need to be scalable to handle increasing data volumes and adapt to new challenges and technologies.

To address these gaps, the main activities during the PHANTEON project will focus on improving data integration and interoperability, enhancing cybersecurity measures and developing standardised risk assessment frameworks.

3 EU PROJECTS RELEVANT TO PANTHEON AND COMPLIANCE WITH PANTHEON TECHNOLOGIES

In this chapter, an attempt is made to document the outcomes of projects similar to PANTHEON. These projects are chosen on the basis of two criteria:

1. Projects under the same call and topic as PANTHEON i.e., Horizon Europe Framework Programme, Disaster-Resilient Society (HORIZON-CL3-DRS-01) or earlier e.g., SU DRS01-2018-2019-2020.
2. Projects, which, although are not under the same topic as PANTHEON, have delivered technological outcomes, similar to the ones that this project aims to develop.

The list and short description of these projects is not exhaustive but indicative and includes endeavours, which are either ongoing and reaching their final stage or have recently ended. The reason behind the selection of current and recently finished projects is to document the state-of-the-art and up to date technological outcomes and, furthermore, to depict the common grounds and the way in which Pantheon complements and goes one step further leveraging state-of-the-art solutions in community-based disaster risk management.

3.1 DOCUMENTATION OF EU PROJECTS TECHNOLOGICAL OUTCOMES

The focus of this subchapter is on the technological outputs of EU projects, which are similar to PANTHEON, without, however, excluding other types of results e.g., procedural solutions, guidelines and recommendations. The following table presents the selected projects as well as the call and topic, under which these projects are funded.

Table 1: Projects with significant correlation to Pantheon

Call	Topic	Project
H2020-SU-SEC-2018-2019-2020	SU-DRS01-2018-2019-2020- Human factors and social, societal and organisational aspects for disaster-resilient societies	BuildERS, Building European communities' resilience and social capital
		RiskPACC, Integrating risk perception and action to enhance civil protection-citizen interaction
		ENGAGE, Engage society for risk awareness and resilience
		LINKS, Strengthening links between technologies and society for European disaster resilience
	SU-DRS02-2018-2019-2020 - Technologies for first responders	FASTER, First responder advanced technologies for safe and efficient emergency response
		RESPOND A, Next-generation equipment tools and mission-critical strategies for first responders
H2020-SU-INFRA-2018-2019-2020	SU-INFRA01-2018-2019-2020 - Prevention, detection, response and mitigation of combined	PRECINCT, Preparedness and resilience enforcement for critical infrastructure cascading cyberphysical threats and effects

	physical and cyber threats to critical infrastructure in Europe	with focus on district or regional protection
Directorate General for European Civil Protection and Civil Aid Operations	Union Civil Protection Mechanism Prevention and Preparedness Projects in Civil Protection and Marine Pollution 2018-2020	AIDERS, Real-time artificial intelligence for decision support via RPAS data analytics
		LODE, Loss data enhancement for DRR & CCA management

3.1.1 BUILDERS PROJECT

Builders was a H2020 project under the topic "SU-DRS01-2018-2019-2020- Human factors and social, societal and organisational aspects for disaster-resilient societies" aiming to strengthen citizens' resilience and the overall capacity of the society. The core focus of the project was to identify the needs of vulnerable groups and, through a multi-stakeholder approach, to address these gaps, support and amplify the capabilities of these groups against future threats. Through the interaction with the vulnerable segments of the society and their representatives, the project achieved to produce a variety of innovations and results, both technological, e.g., specific systems and platforms to support first responders and also the public in cases of emergencies, and procedural e.g., specific guidelines with the aim to build and strengthen bonds between disaster management specialists and other actors (CORDIS EU research results, 2022).

Project Results

According to the project Deliverable 5.2 "Innovation Policy Recommendations" (The Consortium of the Builders Project, 2019) the project has developed a variety of solutions, which can be clustered into three categories of innovations, the process and market innovations. As process innovations are described those that are not solutions in the form of products, but have a more procedural aspect, providing guidelines for disaster management stakeholders. Market innovations are actual disaster management technological systems, which were developed by the Consortium of the project, whereas research innovations mainly address researchers and other stakeholders involved in similar projects and provide guidelines for ethical assurance.

Process Innovations of the Builders Project

During the lifetime of Builders seven process innovations were produced: the Vulnerability Assessment Tool, the Inclusive Crisis Communication Canvas, Guidelines for Collaborating with Social Media Influencers, Prototype of a First Responder Training Program, the Builders Board Game for students' training, a Cost Benefit Analysis Framework for using Technologies in Disaster Management and Ethical Guidelines for Policy Formulation (The Consortium of the Builders Project, 2019).

The Vulnerability Assessment Tool was developed with a joint effort among researchers, authorities and non-profit organisations. This multi-stakeholder approach was used in order to define gaps and challenges related to vulnerability assessment and, to that end, 22 interviews, two focus groups and one tabletop exercise, comprising of 46 experts and three different scenarios, took place with the aim to test the tool. The revised version of the tool was presented at a virtual workshop, in which 35 persons from different levels of governance, from the local to the national, participated. The participants provided valuable feedback during the evaluation of the tool, emphasising on the added value it brings to stakeholders assigned to develop disaster management plans, from first responders' organisations to critical infrastructure operators and governmental bodies (The Consortium of the Builders Project, 2019).

The Inclusive Crisis Communication Canvas was developed, building on previous experience, with the aim to support first responders in crisis communication. The tool facilitates communication between first responders and vulnerable groups and their representatives with the aim to establish better understanding and collaboration and strengthen communication between the aforementioned groups.

Social media influencers with thousands of followers can assist in disaster management in various ways, something that is recognised also by the EU (The European Commission). During disasters the spread of false news is observed, something that can have very serious consequences. On the other hand, influencers can make good use of disaster-related information, share their experiences, debunk conspiracy theories and affect the perspective of the community. Builders project has developed specific guidelines for practitioners with the aim to strengthen their cooperation with influencers and exploit the capabilities that social media provide (The Consortium of the Builders Project, 2019).

Within Builders also a training tool for first responders has been developed, which consists of two basic modules:

1. A simulation-based module for external communication and collaboration, consisting of a preparedness drill. The aim is for first responders to increase their skills in communicating and collaborating with vulnerable people and their representatives.
2. An e-learning programme for field operations officers who interact with victims, to increase their communication abilities when they interact with people with specific disabilities and mental disorders.

In addition to the previous innovations the project has also developed a board game for children and students aged between five and ten years old. The game provides, in an entertaining way, information and guidelines for children to increase their knowledge and awareness of emergency situations. A series of questions with a gradual level of difficulty and complexity, depending on the age of the player, have been developed. The game was produced in five languages (English, Finnish, German, Italian and Hungarian) and distributed in countries, where these languages are spoken (The Consortium of the Builders Project, 2019).

BuildERS has developed a cost-benefit framework for authorities that are charged with the decision on the procurement of state-of-the-art systems and tools for the management of disasters. Such technologies include, inter alia, UxVs and sensing technologies, crowdsourcing and data sharing systems, blockchain technologies and land-positioning systems. The framework is based on specific aspects that have to be addressed including the provider of a solution, its usage, benefits, imposed risks, probable further developments, its cost and cost-benefit ratios.

Since the project greatly targets vulnerable groups, ethics play an important role for the proper management of the results of the project. Guidelines for the ethical assurance in inclusive RDI-projects, developed within the project, provide added value not only for BuildERS but for other similar projects as well and should be considered for PANTHEON as well, for an ethical monitoring of its tasks and outcomes.

Market Innovations of the BuildERS Project

Market innovations are actually the core technological outcomes of the project. They are tools, which can be further developed and sold in the market. Moreover, the combination of these products with the process innovations of Builders can provide a more holistic approach in disaster management (The Consortium of the Builders Project, 2019).

The Natural Disaster Mapping Tool is one of the three market innovations of the project. The aim of the tool was to be used by practitioners, other than official first responders, who do not have straight access to classified data. In order to deploy their resources and personnel, practitioners need to integrate and utilise heterogeneous data coming from a variety of sources e.g., public data. The aforementioned tool provides and combines maps from these sources, thus depicting the overall situation and the evolution of a disaster. These maps consist of several layers which present, among others, the current status of the disaster, capitalising on satellite imagery and GIS technologies, e.g., the Copernicus Emergency Management Service or the Earthquake database from the United States Geology Survey, operational centres and locations of relief agencies and the likelihood of high concentration of vulnerable people in specific locations. The latter derive from population density and socio-economic data and provide information, inter alia, about homeless people, foreigners with language issues. However, in order this tool to be effective for the end users it has to be continuously updated and the collected information for the needed updates to be collected in an ethically accepted manner (The Consortium of the Builders Project, 2019).

Mobile phone positioning data is another crucial source of information to identify and locate people who are in need of help. For that reason, the consortium developed two tools, which enable the assessment of the location, time and the number of people that require assistance.

The first tool makes use of historical mobile positioning data. Historical can be translated as data that showcase the number of residents, commuters and visitors of a particular area. They are gathered by network operators, using the records of phones connected to specific cell towers at a given time, thus enabling a temporal and geographical dimension. The tool provides patterns of the volumes of people moving in and out of an area on a daily, weekly and seasonal scale. First responders can have the overall picture of the distribution of the population and assess the location and the number of resources to be deployed in an emergency. For the testing and validation of the tool, a tabletop exercise was organised with the participation of eight organisations in Estonia (The Consortium of the Builders Project, 2019). The system provides added value, especially at the pre-catastrophic phases, as it enables stakeholders, associated with disaster management, to analyse peoples' behaviours during past events and identify differences with normal behaviour.

Whereas the Mobile Positioning Dashboard is a tool using historical data, the SaveMyLife application, also developed by the BuildERS consortium, uses real-time data. The application has three main features: pre-loaded content, a panic button and an early warning system. Regarding the pre-loaded content, it includes information about safety points e.g., hospitals and police stations, as well as the time to reach these points. Real-time updates and early warning are issued based on updates of the emergency, provided by official authorities. The panic button can be used to notify and inform first responders and emergency authorities that the person requires assistance. With the information that the user registers in the application, the victim's location is accurately detected, while a categorisation, based on the health status, age and special needs of the users, is enabled, thus facilitating first responders to assess and prioritise where and when to deploy their resources (The Consortium of the Builders Project, 2019).

3.1.2 RISKPACC PROJECT

RiskPACC is a three-year project under the topic "SU-DRS01-2018-2019-2020 – Human factors and social, societal and organisational aspects for disaster-resilient societies", which started in September 2020 and consists of 20 partners from 9 countries across Europe. The upper goal of the RiskPACC project is to further understand and close the gaps between the risk perceptions and actions of citizens and among citizens and Civil Protection Authorities (CPAs) to enhance individual and collective disaster resilience (EC CORDIS, n.d.).

The project supports a co-creation approach to facilitate interaction and collaboration between citizens and CPAs in order to detect their needs and develops technical novel solutions to build enhanced disaster resilience. The "Risk Pack" of solutions that is being designed within the project includes a framework and methodology to understand and close the Risk Perception Action Gap (RPAG), a repository of international best practices, tooled solutions based on new forms of digital and community-centred data and an associated training guidance.

Project results

RiskPACC has highlighted some key gaps between CPAs and citizens regarding risk perception, actions and risk management processes and strategies. To bridge this RPAG and to enhance CPAs and citizens' collaboration, the RiskPACC project defines a collaborative framework, providing a more functional way to organise activities, tools and processes. The basic structure of the framework consists of four modules: Understanding, Sharing, Relating and Building which are expected to be finalised by the end of the project. The following figure depicts the collaborative framework of the project (The Consortium of the RiskPACC Project, 2022).

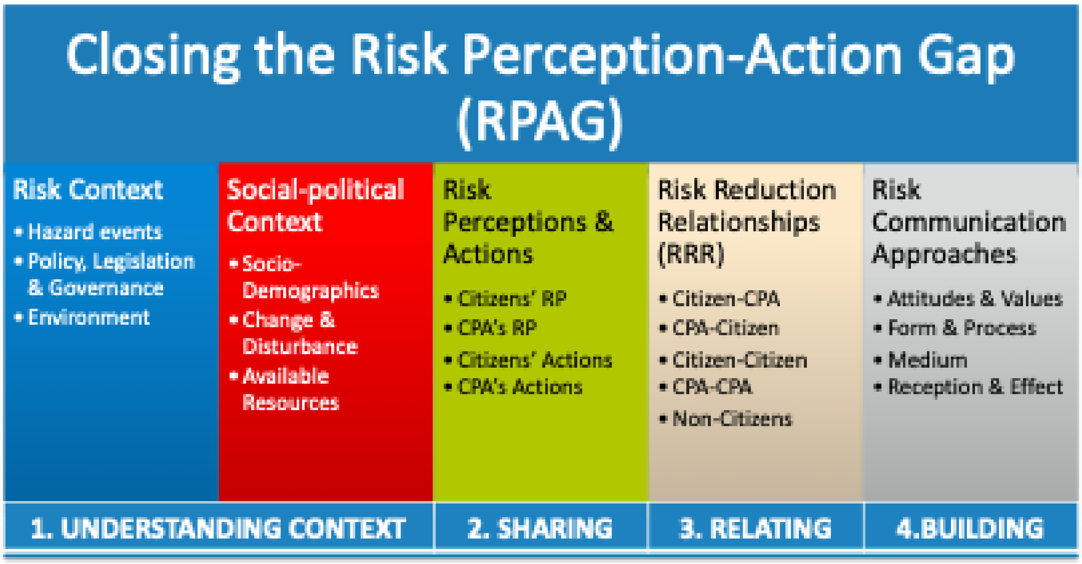


Figure 8: RiskPACC Collaborative Framework, Source: RiskPACC D4.2

RiskPACC is framed by five crowd-sourcing solutions, the HERMES platform, the Aeolian AR mobile app, the PublicSonar platform, and two Volunteered Geographic Information tools, the MappingDamage Tool and the Thermal Comfort Tracker Tool, based on the needs assessment and input from the co-creation labs, which are designed to narrow down the perception-action gaps. The overall architecture of RiskPACC provides that these technological tools will be supported under the umbrella of the new platform that will be created within the project.

The functionalities, as well as the development and integration of these technological tools were determined through the detected needs and requirements that were identified in the three rounds of workshops that were held for each of the seven use cases of the project in different time periods. The participation of a large variety of stakeholders, from different organisations and with different backgrounds, was vital to the determination of the requirements and the provision of guidelines on technical developments.

1. HERMES Platform

HERMES is an open innovation tool, a social media web-based platform, designed to facilitate and improve sufficient communication between CPAs and citizens in a safer, improved and faster manner. The tool is based on the promotion of community engagement in disaster risk management through information exchange with the aim to assist communities evaluate information about potential hazards and threats in an area, prepare them for and respond to emergencies. The functionalities of HERMES, i.e., profile setup, knowledge repository, alert systems, and message exchange between CPAs and citizens, enhance disaster preparedness and response activities.

To ensure the longevity of the app, future collaboration with local governments and agencies is sought, as well as encouragement of ongoing support and update of best practices within the repository (The Consortium of the RiskPACC Project, 2023).

2. AEOLIAN AR mobile application

AEOLIAN AR mobile app is a tool based on AR technology. Functionalities, such as the provision of real-time information, the alert system, the upload of training material, among others, aim to enhance situational awareness and decision-making during natural and man-made disasters. The Aeolian AR app has been aligned with the identified needs and the interactions between CPAs, volunteers, citizens and different vulnerable groups through the co-creation workshops. The application, after the second round of workshops, has reached TRL 6.

For the continuous optimisation of the app and in order to be able to provide real-time data and to support a large volume of users, especially in emergency situations, the app should be constantly updated (The Consortium of the RiskPACC Project, 2023).

3. PublicSonar platform

PublicSonar platform is a cloud-based online application, able to analyse millions of web data, including data from social media and monitoring reports and provide real-time information about emergencies and tracking of hazards, searchable in a wide range of foreign languages. Risk perception can be assessed even through recognition and sentiment analysis of people’s positive and negative emotions. In addition, the app delivers functionalities such as informing about the lack or availability of resources.

Sentiment analysis enhances two-way communication between citizens and CPAs, as it delivers the ability to analyse and evaluate the emotions of the public, views and attitudes, providing insights about their perception of risks and hazards, helping CPAs on the other hand on developing a more holistic communication strategy tailored to their needs. Analysing citizens’ sentiments and measuring the level of trust and credibility enables CPAs to adopt a more transparent, credible and responsible place.

The sentiment technology of the PublicSonar platform helps to close the RPAG through comprehensive sentiment measurement before and after an incident, in-depth analysis of negative sentiments helping to understand the underlying issues and challenges, flexible user interface, scalability and adaptability aligned with the ongoing digital landscape.

The main PublicSonar tool was in TRL 9 since the beginning of the project, with some functionalities at a lower level, such as the multi-language support and the key search language in the semantic search engine (The Consortium of the RIskPACC Project, 2023).

4. **MappingDamage tool**

MappingDamage is an assessment tool for pre- and post-disaster damages for basic infrastructures, e.g., buildings, roads, vehicles, and fire hydrants, focused on wildfires and floods. The tool relies on volunteer citizens' engagement and their collaboration with CPAs, in order to provide them with valuable information and support them prioritise damages and facilitate them in reconstruction and recovery and in decision making (The Consortium of the RIskPACC Project, 2023).

5. **Thermal Comfort Tracker tool**

Thermal Comfort Tracker tool is utilised for monitoring data collected from meteorological sensors, which measure air temperature, air speed, and humidity to calculate the subjective perceptions of thermal comfort. Studying and understanding people's perception of thermal comfort can provide valuable information in policymakers' strategies and sustainable practices to mitigate the impacts of heatwaves on the environment (The Consortium of the RIskPACC Project, 2023).

It is vital, however, that the tools developed under the RiskPACC are constantly updated and improved with the aim to be more effective in disaster risk reduction efforts and to be able to support a large number of users, including people from vulnerable groups, elderly, people that leave in remote areas with limited access to the internet.

3.1.3 ENGAGE PROJECT

ENGAGE was launched in July 2020 and is a three-year EU-funded research project studying societal resilience. The ENGAGE consortium brings together the expertise of 14 partners across 8 European countries. The project considers resilience as an intrinsic ability of society to adjust its functioning and sustain operations before, during and after disasters. ENGAGE will deliver its results as stand-alone outcomes and integrated in a knowledge platform, containing guidance on how to improve societal resilience in different cultural contexts (ENGAGE, n.d.).

In addition to the knowledge platform, the stand-alone results that ENGAGE aims to deliver are methods of improving societal resilience, which refer to the ability of a society or community to withstand and recover from various shocks, stresses and disruptions, best practices for communication and social media, a catalogue of solutions for societal resilience, including recommended guidelines, practices, processes, strategies, methods and tools aimed at first responders and authorities, validated ENGAGE solutions and examples of applications, guidelines for achieving societal resilience and a Knowledge Innovation Community of Practice (KI-CoP) including practitioners, NGOs, VOSTs, scientists, and citizens' representatives supporting ENGAGE as users and co-owners of its solutions (ENGAGE, n.d.).

Project results

As the project is still ongoing its results and outcomes are documented based on publicly available Deliverables.

1. **Preliminary Model of Societal Resilience**

A first basic output of ENGAGE is the preliminary model of societal resilience presented in the following figure.

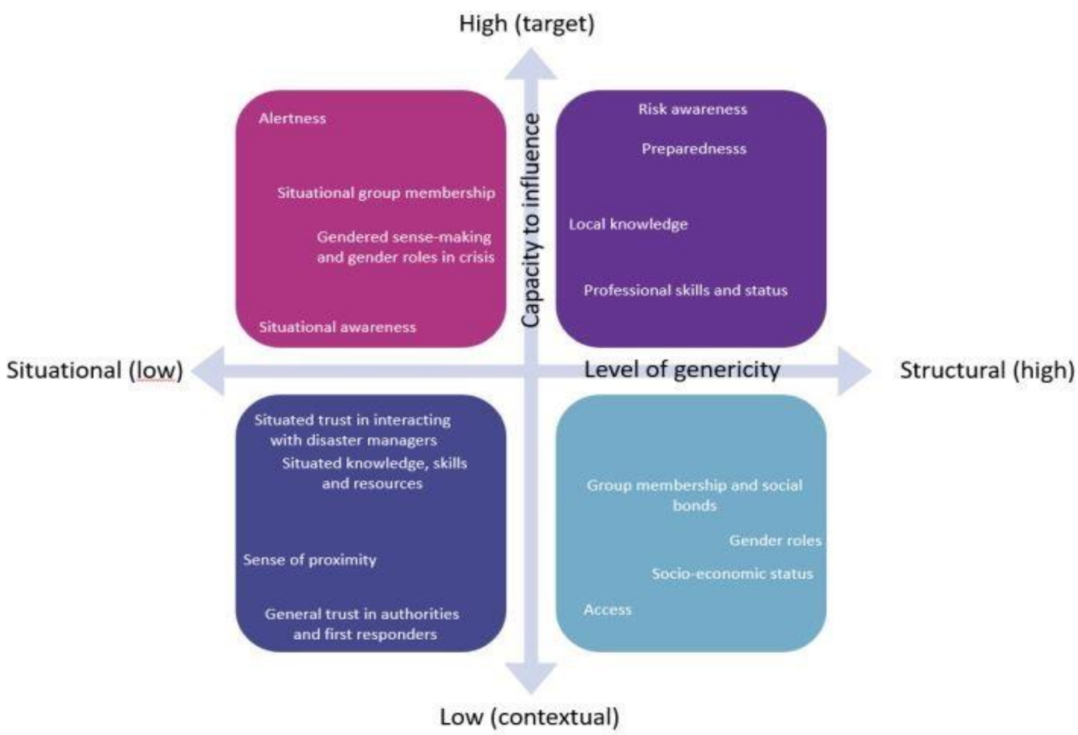


Figure 9: Preliminary model for assessing and methods form improving societal resilience, Source: [ENGAGE D1.1]

Figure 9 describes how these contextual aspects of societal resilience can be further modelised. They are first situated on a continuum ranging from contextual aspect that should not be targeted for enhancing societal resilience to target aspects that can be influenced by the type of solutions ENGAGE proposes. A typical example of a contextual aspect that cannot directly be influenced would be general trust in authorities and first responders. However, the way that trust is created in interacting with first responders can, to a certain extent, be modified, even though it is rooted back in the general conception of trustworthiness. Risk awareness and preparedness can as well be targeted, but the socioeconomic resources, on which they depend on, are out of reach for the solutions ENGAGE intents to produce. This continuum also permits the differentiation of group memberships into primarily permanent ones, such as individuals belonging to a specific religious group, and more temporary ones that become relevant during a crisis. These aspects are further positioned on a second continuum that gauges their level of generality. This distinction enables to separate aspects that are inherent to the societal structure from those that emerge specifically in times of crisis. For instance, gender may assign particular roles to citizens during a crisis, but the way these roles are enacted can vary significantly depending on the specific circumstances. It is important to note that having awareness of certain risks does not automatically translate to situational awareness. As a result, this initial model allows to assess the elements that contribute to societal resilience and compare different case studies while preserving the unique characteristics of each individual case.

2. Communication, the role of social media and best practises

One of the goals of ENGAGE is to understand the role of communication in building societal resilience, in particular through social media. More broadly, the goal is to understand the communication needs and expectations of the public and the use of various communication channels to fulfil their information needs. Moreover, the aim is to create guidelines and recommendations for effective communication means with impacted societies, either those that have already been impacted by a disaster or are under potential risk.

According to the ENGAGE D1.3 "Communication, Social Media and Societal Resilience among Citizens" (The Consortium of the ENGAGE Project, 2021) there were five objectives:

- The first objective was to identify the communication needs and expectations among community members and between them and the authorities and first responders. The study results, both quantitative and qualitative, showed the various communication needs and expectations of the public, ranked their importance in the eyes of the society and revealed other communication needs to be expressed in social media discussion. The implication drawn from these findings is that authorities and first responders need to address a range of needs, including those that may not be considered highly significant by the public but were expressed as predominant concerns in electronic communications on social media accounts of authorities and first responders.
- The second objective was to determine the favoured sources for obtaining information and warnings regarding emergencies and disasters. Similar to the communication needs and expectations, a hierarchical order of preference was observed. Among the platforms examined in this particular focus, social media ranked second to last, before printed media, but after television and face-to-face communication. On the other hand, with mobile phones as the most preferred source for information, these findings emphasise that the variety of communication channels is essential, with many traditional channels that are still preferred more than new media. This is important because many authorities and first responders started publishing more content on social media at the expense of traditional media. The findings of this study suggest reconsidering such decisions, uncommonly since the different communication channels were correlated with other communication needs.
- The third objective was to understand effective communication characteristics with impacted societies and identify prominent illustrations of such communications. Here, the analysis, predominantly qualitative, addressed the multiplexity of communication needs. As mentioned before, since on one hand, communication needs were ranked in a specific order by the public, but on the other, the dominance of these needs in actual comments was different – the project identified effective communication as addressing the communication needs in a multiplex way: allowing the public to fulfil a comprehensive set of needs, by interacting and engaging with the content.
- The fourth objective was to define both the communication process among community members and between community members and operational authorities and its impact on societal resilience. This was done in an illustration connecting the internal, community members, communication process, and the external, with the authorities and first responders, communication process. The conclusions here are that one type of communication process facilitates the other, and it will be considered as a mistake to focus only on one.
- Finally, the fifth objective was to identify the role of gender, socioeconomic status, culture, digital literacy and other demographic variables on the aforementioned objectives. Digital literacy and gender played the most crucial role, while nationality and socioeconomic status were less dominant. The conclusion here is the need to focus more on gender and digital literacy questions over traditional factors, such as nationality and income.

3. Catalogue of Formal and Informal solutions

The outcomes of the ENGAGE analysis for all the formal solutions identified for improving the interaction of emergency organisations and authorities with the society. These solutions have been gathered from different sources and they have been classified into different groups of solutions based on their nature. These solution groups were merged and unified to have just one classification for the overall analysis. Table 2 shows the merging and the unification carried out (The Consortium of the Engage Project, 2021).

Table 2: Formal solutions to improve societal resilience, Source: Engage D2.2

Final type of solution	Types of solutions included within this group				
Web platform	Web app	Platforms	Web platforms	Portfolio of solutions	
Apps	Apps	Mobile apps			
Guidelines	Guidelines	Book			
Framework	Framework				
Media	Social media channels	Messaging apps	Media		
Community of practice	Community of practice				
Services to reach society	Services to reach society				
Awareness and training campaigns	Awareness and training sessions	Awareness campaigns	School campaigns		
Plans and strategies	Disaster management plans and strategies	Disaster management plans			
Collaborative methods and technologies	Collaborative methods to work with stakeholders	Collaborative technologies	Community relations	Volunteers management	Crowdsourcing
Alert system	Alert systems				
Call centres	Call centres				
Incentives	Funding programme	Governmental programme			

Related to this information, Figure 10 presents an overview of the magnitude of the solutions identified from each source. 49 solutions were obtained from the interviews, 35 from the end-user survey and 42 from the workshops, concretely 20 from the end-user workshop, and 22 from the KICoP workshop. In total, 126 solutions come from methods applied involving end-users, and only 42 come from the scientific and grey literature. From this, it can be deduced that there is a lack of research about the solutions to improve the interaction of emergency organizations and authorities.

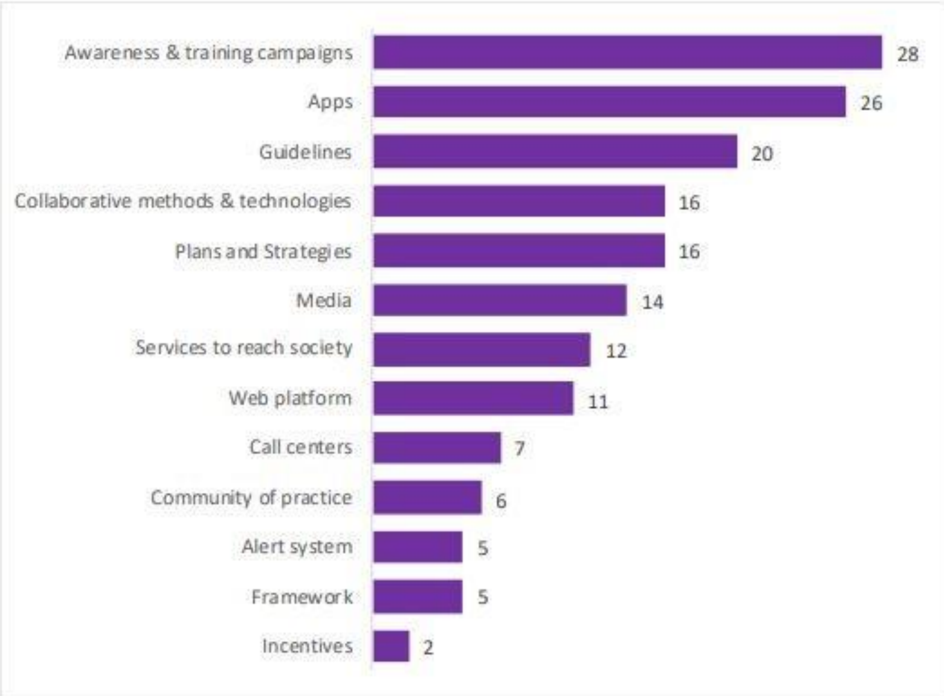


Figure 10: Distribution of the collected formal solutions, Source: ENGAGE D2.2

4. Knowledge and Innovation Community of Practice (KI-CoP) platform

The overall aim of ENGAGE is to link informal resilience, inherent in society, with the efforts of formal authorities. In this regard, an important objective of the ENGAGE catalogue of solutions is to provide a knowledge repository summarising and highlighting solutions that could help key actors in achieving this. Figure 11 provides an overview of the main aims of the catalogue e.g., tools, methods, apps, guidelines. Thus, the catalogue provides both a set of solutions that are presented with relevant basic information and a selection of these which are more in-depth characterised. The in-depth characterised solutions are presented with contextual guidance that will aid users of the catalogue to find a solution relevant to their local context. The content from the catalogue is publicly available in the online ENGAGE Knowledge Platform.

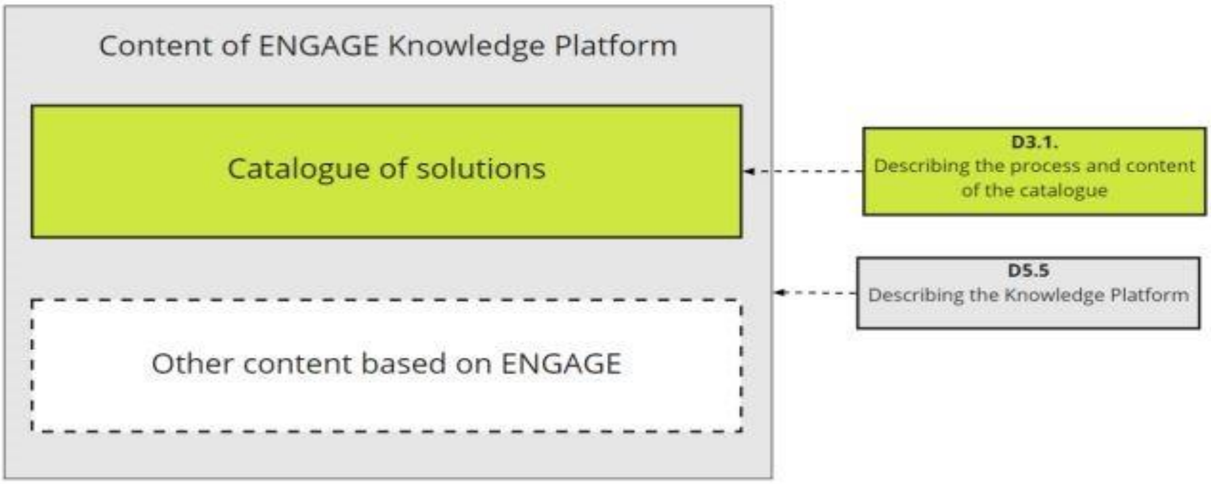


Figure 11: Catalogue of solutions, Source: Engage Knowledge Platform

3.1.4 PRECINCT PROJECT

EU Critical Infrastructures (CIs) are becoming more and more vulnerable to physical and cyber-attacks as well as natural disasters. The focus of research and newly developed solutions is on the protection of individual CIs, however as most of the CI interrelationships have grown more intricate and rely on interconnected networks and devices, the failures in a critical sector may result in cross-sector -or even cross-border-cascading effects. The lack of proper awareness makes it difficult for operators to anticipate risks, protect critical services of the CI and enable rapid recovery in the event of disruptions.

PRECINCT, or “Preparedness and Resilience Enforcement for Critical Infrastructures Cascading Cyberphysical Threats and effects with focus on district or regional protection” as its full title is, is one of the eight projects which was funded under the “H2020-SU-INFRA-2018-2019-2020” call and the “SU-INFRA01-2018-2019-2020 – Prevention, detection, response and mitigation of combined physical and cyber threats to critical infrastructures in Europe” topic. The project was initiated in October 2021 and will end in September 2023. The application of the PRECINCT project methodological framework and technological solutions developed aims at improving the phases of crisis management that deal with the preparedness and response capabilities of interconnected CI’s operating in the same geo-graphical area (PRECINCT, n.d.).

Project Results

PRECINCT aims at delivering:

- Digital Twins, representing the CIs’ network topology and metadata profiles by applying closed-loop ML techniques to detect violations and provide optimised response and mitigation measures and automated forensics.
- A Cross-Facility collaborative cyber-physical Security and Resilience management Infrastructure enabling CI stakeholder communities to create AI-enabled PRECINCT Ecosystems and enhanced resilience support services.
- A vulnerability assessment tool that uses serious games to identify potential vulnerabilities to cascading effects and to quantify resilience enhancement measures.
- Smart Ecosystems, deployed in four large-scale Living Labs (LL) and Transferability Validation Demonstrators. The developed ecosystems will actualise Digital Twins corresponding to the relevant CIs in each LL and give measurement-based evidence of the targeted advantages.
- Sustainability related outputs including Capacity Building, Dissemination, Exploitation, Resilience Strategy, Policy/ Standardisation recommendations.

The Digital Twin instantiation in the PRECINT project is tailored to a specific use/context associated with each LL. The Digital Twin Library of components is a collection of all objects and models that are utilised in customised Digital Twin instantiations. The PRECINCT Digital Twin Architecture consists of several tools including AI tools, serious games and cyber physical threat protection tools among others. The primary goal is to identify abnormal behaviour, disruptive incidents and potential security issues in the CI network and to give operators or virtual agents with plans or actions to be done in order to reduce the impact of those threats or risks on the CI network (Luong Nguyen).

The hesitation to adopt AI techniques across large critical infrastructure systems may be addressed if AI is understood in the context of what it is and is not. The utility of an AI agent is judged in terms of its capacity to achieve a goal, which is typically related with the optimisation of mathematical functions that attempt to describe reality despite their limits. AI is utilised in PRECINCT to identify potential risks in the critical infrastructure network. The purpose in this situation is to find observations that differ from what are considered regular trends. This issue is addressed by using supervised learning algorithms, which, given a collection of labelled observations, may learn to detect potential cyberattacks based on prior experience. Furthermore, AI is used to plan a sequence of actions that could improve the operational state of the critical infrastructures network in the presence of disruptive events. The AI agents, in this case, are said to act rationally when the sequence of actions suggested improves the operational state of the network, thus improving its overall capacity. Lastly, AI is used to identify vulnerabilities from play records obtained from the serious game developed in the project. Here, the agent is said to act rationally if it uncovers patterns from play records that help the operators to identify new vulnerabilities in the systems. In conclusion, AI in PRECINCT seeks to provide critical infrastructure operators with timely information, derived from data, that guides human judgement in the decision-making process, including predictive maintenance, what-if scenarios, anticipating any incident and plan its correction. Identifying patterns that help operators bring critical infrastructure assets to their optimal state also translates into a return of investment (The Consortium of the PRECINCT Project, 2023).

Current research in the protection of Critical Infrastructures (CIs) focuses more and more on resilience. PRECINCT aims to improve CIs resilience using a serious gaming approach for smart cities to achieve their sustainable development goals. The serious game architecture is divided into the front end and the back-end components. Serious Games provide an interactive user interface that integrates and communicates with simulations on the back end through an interactive DSS and scenario specification/building process. Game client development includes the development of the serious gaming front-end in accordance with the Game Design Document, and the back end for storing and analysing individual user interactions. For client development and development architecture, Unity Engine and the corresponding libraries and frameworks for game programming will be used (Soroudi, 2023).

In addition, in PRECINCT, a Resilience Methodological Framework (RMF) has been developed that assesses the resilience of a network of connected CIs (The Consortium of the PRECINCT Project, 2023). The resilience quantification is supported by a probabilistic Cascading Effects Simulation (CES). The CES uses an interdependency graph that models how the involved CIs depend on each other in the sense that a problem in one CI, e.g., if a service is only partly available, may propagate to the other CI. Based on the knowledge of the local dynamics of each component, the CES mimics the propagation through the entire network over time. The availability of a node is described through a state and the local dynamics then describes how this state changes. Information on resilience may influence the local dynamics, so that the CES can also benefit from the RMF. In more detail, a combination of CES and RMF yields the following benefits:

- The interdependency graph provides context and supports quantification of services, which are key steps in the RMF. The simulation results, which estimate direct and indirect consequences of an incident, provide relevant information for setting resilience targets.
- The local dynamics of a node represented by the transition matrix may now depend on information about resilience, i.e., conditional transition probabilities can be used. The intuition behind this is that well protected nodes with increased resilience react less strongly to incidents, i.e., the chance that they switch to a bad state is smaller if the resilience increases.

In PRECINCT, the CES tool is extended to capture the described interaction with the RMF. On one hand, all quantities relevant for the resilience computation are stored and collected and the resulting resilience is computed and returned as a result. On the other hand, the network may contain indicator nodes that describe the resilience level of another (normal) node and hence influence its behaviour.

3.1.5 AIDERS PROJECT

The DG ECHO AIDERS (Jan. 2020 - Oct. 2022) was a 34-month project focusing on the development of a technologically advanced solution for first responders seeking to introduce Remotely Piloted Aircraft System (RPAS) units into their operations and quickly stumble upon the deluge of collected data and rely merely on snapshots to inform incident commanders of the situation in the field. AIDERS was funded from the European Union Civil Protection Call for proposals UCPM-2019-PP-AG for prevention and preparedness projects in the field of civil protection and marine pollution. The AIDERS project aimed at developing application-specific algorithms and novel mapping platform that harness the large volume of data that first responders are able to collect through heterogeneous sensors (including visual, thermal and multispectral cameras, LIDAR, CBRN sensors, etc.) onboard RPAS units and converting that data into actionable decisions for improved emergency response. To address this challenge, this project capitalised on:

1) the long-lasting collaboration between first responders and technical partners of the consortium to identify which information needs to be extracted from the collected data

2) the designed online machine learning algorithms for the processing and analysis of the received data in real-time in order to build situational maps

3) implemented novel visualisations which the higher command can use with the aim to take intelligent decisions.

Project Results

The primary outcome of the AIDERS project was the development of a novel open-source AI toolkit which consists of algorithms and knowledge maps that harness the large volume of data that first responders usually collect through heterogeneous sensors onboard RPAS units and automatically process and convert that data into actionable decisions for improved emergency response. Furthermore, the AIDERS project helped to raise awareness for AI techniques and algorithms and their potential use to enable well-informed decisions and support well-planned response strategies during emergency response. The tools offered through the AIDERS AI toolkit enable incident commanders and first responders to collect and analyse real-time emergency response data from sensors onboard UAVs and build knowledge maps to devise effective response plans. The AI Toolkit is an ICT-based solution that includes advanced ground control data analytics and visualisation applications, which are expected to facilitate and expedite disaster response. The individual tools of the AI toolkit provide standalone features for RPAS-based intelligent data collection and processing, as well as ground control-based enhanced data analytics and visualisation. Specifically, the AI toolkit consists of tools for command-and-control of UAVs and visualisation. The command-and-control tools enable the user to manage a team of UAVs for various missions, such as aerial data collection, SAR operations, area monitoring, etc. The visualisation tools provide the users with better situational awareness that helps them focus on its mission (The Consortium of the AIDERS Project).

Throughout the project, several field exercises took place to evaluate the integration and performance of the AIDERS AI toolkit with the active participation and close interaction of first responder experts, allowing the design of an intuitive and user-friendly solution for collecting, processing, and analysing emergency response data. Lastly, several training activities for first responder professionals have been organised to familiarise them with the developed AI toolkit and help them become highly confident in using it in the field and under challenging circumstances. Overall, the project received significant interest from the community, with positive feedback and numerous expressions of interest for future collaborations on the subject matter.

1. Needs assessment and value of AI algorithms in situational awareness

To develop the envisioned AI toolkit, the project partners conducted several interviews with first responders' members of the consortium and collaborators to understand their needs and requirements and the emergency scenarios that the toolkit needs to address. Based on the outcomes, three disaster scenarios, i.e., large-scale fires, floods, and earthquakes have been identified to have the most pressing needs. After an in-depth analysis, the information required for each disaster has been identified for effective response as well as the various RPAS sensors and data that must be collected and processed to extract the relevant information. With the above into consideration, the AIDERS team has developed AI algorithms to process the collected data in real-time, either onboard drones or at the ground command and control devices, with the aim to enable situational awareness and informed decision making which have been compiled into the AIDERS AI toolkit.

2. Design and development of a novel AI toolkit

The AIDERS AI toolkit provides relevant, reliable and timely information from data collected through sensors onboard drones. It uses real-time data analytics and AI algorithms to enable informed decision making by first responders during emergency response. The AI toolkit is a web-based solution with advanced ground control data analytics and visualisation applications, to enable first responders' control multiple RPAS units simultaneously and carry out various missions. For instance, the AI toolkit enables real-time data collection for the disaster area which can be geotagged and become instantly available through the platform. It allows autonomous area monitoring with multiple RPAS units as well as the fast collaborative generation of maps. Computer vision and ML algorithms that have been developed and trained specifically for low-end computing devices allow the identification of objects of interest in real time. Fusing this information with data from the RPAS devices, the detected object of interest is pinpointed on the layer map of the platform allowing first responders to comfortably use them in their situational reports.

3. Testing, Training and Evaluation in field exercises

An important part of the AIDERS project was the continuous testing of the AI toolkit to provide a software reliable and effective. To achieve the desired readiness level of the project, project partners undertook several verification sessions and field exercises. Several features were tested separately and then included in the platform and tested altogether in order to build a stable version of the AI toolkit. Apart from verification tests, several training sessions took place to familiarise first responders with the AIDERS AI toolkit and a workshop has been organized to disseminate the project outcomes (The Consortium of the AIDERS Project).

Figure 12: AIDERS AI Toolkit features and capabilities, Source: [AIDERS D5.3](#)

3.1.6 LINKS PROJECT

LINKS "Strengthening links between technologies and society for European disaster resilience" is a H2020 project under the "SU-DRS01-2018-2019-2020 – Human factors and social, societal and organizational aspects for disaster-resilient societies" and provides a comprehensive study on disaster governance in Europe (LINKS, Strengthening links between technologies and society for European disaster resilience, n.d.). The overall aim of the LINKS project is to strengthen links between technologies and society for improved European disaster resilience, by producing sustainable advanced learning on the use of social media and crowdsourcing (SMCS) in disasters. In order to reach the core objectives of LINKS, the partners followed an integrative research approach, starting from an assessment of the three complementary knowledge domains: Disaster Risk Perception and Vulnerability, Disaster Management Processes and Disaster Community Technologies (DCT). The project developed the LINKS Framework which consists of scientific methods, practical tools and guidelines addressing researchers, practitioners, and policy makers to understand, measure and govern SMCS for disasters. It was developed and evaluated through five practitioner-driven European cases in Denmark, Germany, Italy, and the Netherlands, representing different disaster scenarios. Furthermore, LINKS created the LINKS Community, which brings together a wide variety of stakeholders, both online (LINKS Community Centre) and in person (LINKS Community Workshops).

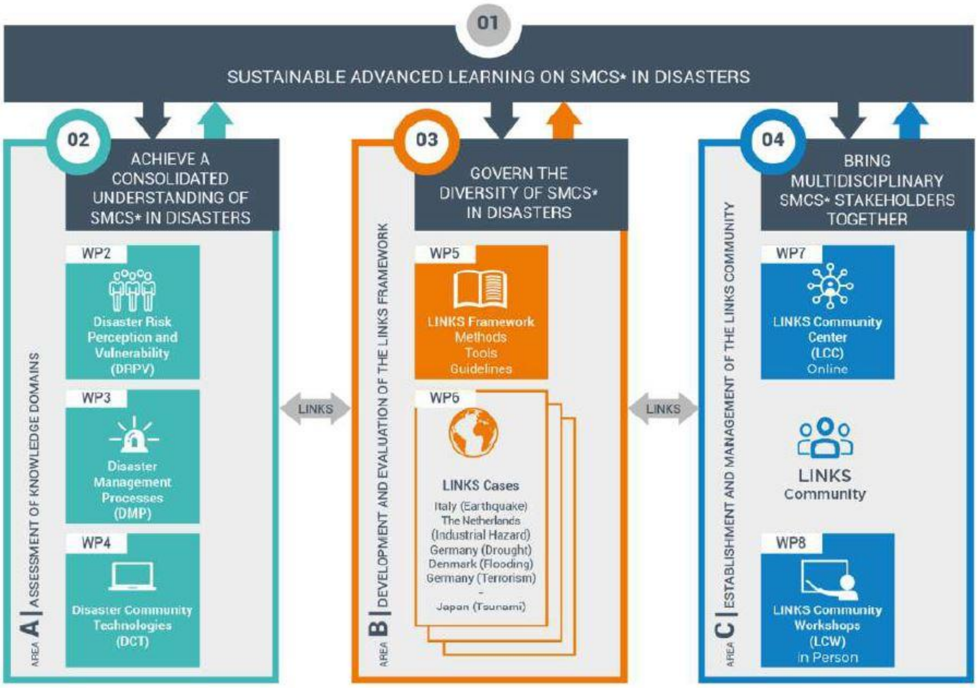


Figure 13: The structure of the project, Source: LINKS Communication Material

Project Results

The project produces the following results:

1. **DCT KNOWLEDGE BASE- A consolidated understanding of disaster community technologies for social media and crowdsourcing.**

DCTs were elaborated and analysed to achieve a consolidated understanding of these technologies and to prepare for the development of the LINKS Framework and the LCC, to achieve sustainable advanced learning on the effective use of SMCS in disasters and ultimately to strengthen societal resilience (The Consortium of the LINKS Project, 2020). The state-of-the-art was developed by a literature review and a business market analysis. The literature review identified significant existing scientific work concerning:

- Good practices when using DCTs in SMCS
- Existing guidelines with a technological view
- Existing IT-classification approaches for a) IT-system in general, b) IT-systems in DMP and c) SMCS analysis technologies
- And negative impacts and challenges of DCT usage in Europe and beyond.

The results of both**,** the literature review as a top-down approach as well as the business market analysis as a bottom-up approach, were consolidated in the draft DCT schema. The DCT-schema enables the classification and comparison of DCTs using an extensive set of categories (The Consortium of the LINKS Project, 2020).

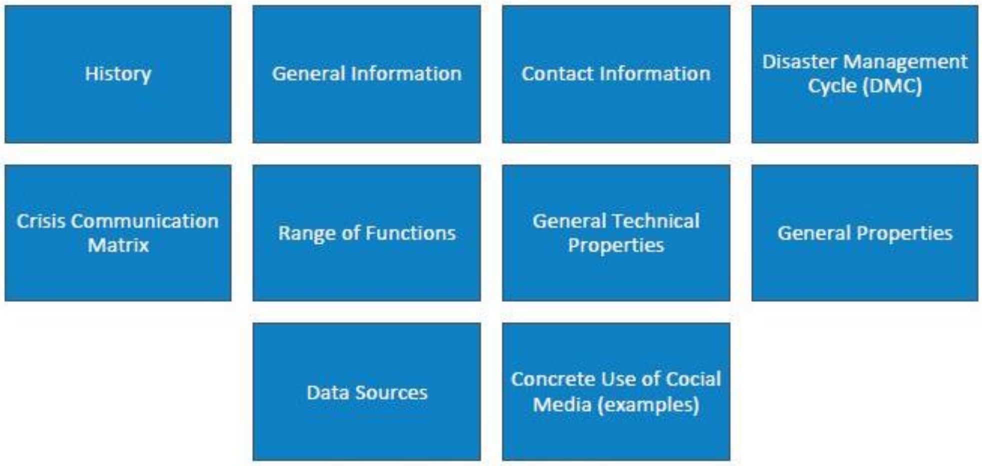


Figure 14: First-level categories of the draft DCT-schema, Source: LINKS D4.1

2. **LINKS Framework**

The Framework provides products for critical stakeholders by combining knowledge and experiences about how SMCS are used in disaster risk management.

Figure 15: Overall approach and framework of the LINKS project, Source: LINKS D2.7

The above approach focuses on the second version of the LINKS Framework that is currently being validated and assessed in order to provide, within July 2023, the final version of the framework. Expected and actual outcomes about the application of the products will be also collected through the activity plan so that needs and gaps can be considered to develop the products and overall Framework further.
The final outputs will come within 2023 with respect to:

- the results from the case assessments to improve the learning paths and the content of the products
- implementation in the LCC
- contribution to already EU existing initiatives
- evaluation and validation

3. LINKS Community Center (LCC)

The key objective of the LINKS project is to build a sustainable, multidisciplinary, stakeholder community consisting of different actors from different countries, professions and schools of thought. The aim of the LINKS Community is to learn and benefit from the project development and results and to provide their knowledge and expertise to improve LINKS research. An important tool for this purpose is the LINKS Community Center (LCC) as it will be the technical foundation for the online community.
The LCC brings together different stakeholders (LINKS Community) in one user-friendly and flexible web-based platform and enables them to exchange knowledge and experiences and to access, discuss and assess learning materials on the usage of SMCS in disasters (The Consortium of the LINKS Project, 2021). The stakeholders will be able to access materials for advanced learning (included in the LINKS Framework), such as methods, ready-implementable tools and easily applicable guidelines to achieve a more effective use of SMCS in disasters. The LCC therefore plays a vital role in creating and fostering a lively community around the LINKS project and the project's results. The final LCC platform outcomes are under preparation.

3.1.7 LODE PROJECT

LODE project stands for "Loss Data Enhancement for DDR and CCA Management". LODE was a 30-months project funded by the Directorate General for European Civil protection and Humanitarian Aid Operations (DG ECHO) of the European Commission, under the Union Civil Protection Mechanism Prevention and Preparedness Projects in Civil Protection and Marine Pollution Program and run from 2018 to 2020.

The focus of the project was on the recovery phase of a disaster by improving the collection, storage, organisation of post-disaster damage and loss data. The technology developed is related with data management and interoperability to support a variety of applications, ranging from accounting to forensic analysis of disasters, to the enhancement of the capacity of risk modelling. This is done following the convincement that has been growing in the last years and stressed in the Sendai Framework for Disaster Risk Reduction (DRR), according to which post-disaster damage and loss data are important components of knowledge and empirical evidence to support a number of national, European and international policies aimed at risk mitigation and climate change adaptation (CCA).

Ten partners are committed to the project from seven Countries, including France, Spain, Finland, Greece, Serbia, Portugal and Italy and they represent both scientific research centres and universities, such as the Consortium of Scientific Research of Spain (CSIC), the University of Porto (Portugal), Polytechnic of Milano (Italy), the Research Center of Territorial Vulnerability (Italy), as well as public administrations that are active in different fields of risk management and mitigation, such as the Civil Protection Authority of the Umbria (Italy) and Catalonia regions (Spain), the Earthquake Planning and Protection Organization (E.P.P.O.) or the Center of Climate Change of the Euro-Mediterranean (CMCC) (LODE Loss Data Enhancement for DRR & CCA management, n.d.).

Project Results

The LODE results were built on prior experience of all partners in collecting, organising and using disaster damage and loss data at different levels of government and on a prior project funded by DG ECHO (call 2014), IDEA "Improving Damage analysis to Enhance cost benefit Analysis" that showed the need to better coordinate efforts from civil authorities. With the involvement of a built network of expert stakeholders, collaborating closely in a three-tier strategy having as the inner core layer the project partners, at the second level the actors of the project showcases and at the third level stakeholders at regional, national, European (such as the DRMKC, DG ECHO and EEA) and international level (OECD and UN), the LODE project generated three main results: the best practices guideline, a set of ten showcases and the LODE information system.

As a first step, members of the experts' network were involved in the evaluation of existing databases and practices for damage and loss data collection and management, in order to identify current gaps and challenges. From them the project partners elicited the key requirements to drive the design and implementation of the LODE information infrastructure for recording loss and damage data from multiple sectors at relevant spatial and temporal scales.

1. Best practices guidelines generated by LODE

The best practices were created to develop a comprehensive picture of damage due to natural hazards and to some effects of climate change, that could be applied by relevant policy and multisector stakeholder organisations responsible for DRR and CCA. By co-developing an in-depth understanding of what is considered damage in different governance, societal and territorial sectors, a successful discussion generated both technical and procedural methods to manage current loss and damage data (The Consortium of the LODE Project, 2019).

Best practices include the required enhancements of the Information System in line with the recent Directive on "Open data and the re-use of public sector information", Directive (EU) 2019/1024. Proposals are given on how to collect, organise, store and use loss and damage data, identifying common elements within different context and methodologies, classifications and indicators. By analysing up to 31 datasets, 8 global including multi-peril loss databases, EM-DAT, NatCat and Sigma, which provide a global coverage for a long time span and are highly cited data inventories in the literature, 5 European, 20 national and 4 regional databases hazard-based or sector-related, the project formalised the gaps and built an enhanced common data structure.

The gaps identified were related to the low availability due to long time span, privacy issues or proprietary data, the reduced spatial or temporal coverage and the lack of consistency and standardised methodologies of data collection. To overcome these gaps, the best practices included the list of requirements of an enhanced Information System organised in:

- General data quality
- Data collection process
- Data organization as relational database
- Data storage and use

2. Set of pilot showcases

The baseline of LODE is a set of ten showcases in all countries of the project partners, where damage data collection, storage and analysis were carried out following the methodology set by the Best Practices tool. In each case, data applications were carried out to show in practice the added value of enhanced damage and loss data, and the utilities provided by an information system constructed within the project. The co-development of the showcases aimed to rationalise what stakeholders already do in the aftermath of a disaster, and to provide more and better opportunities to capitalise on the effort of data collection beyond compensation purposes.

As a conclusion of the showcases exercise, Deliverable 5.3 states that the actual situation is characterised not only by the fragmentation of data but also and more importantly by the fragmentation of responsibilities, in which the strongest influence for data quality lies (The Consortium of the LODE Project, 2021). Disaster data reporting varies in Europe and by sector. These data are part of an administrative, cultural and sectoral tradition specific to each Member State. They also depend on the prerogatives devolved to the public and private sectors.

3. The LODE information system

The LODE information system was a Database Management System designed to be multi-purpose, dynamic and flexible by comprising standardisation, a result of many years of interactions between researchers, stakeholders and developers culminated in the tight development process within the LODE project lifetime.

The tool responded to the need of an improved damage and loss data collection to account for damages according to a precise analysis of current practices, taxonomy and terminologies in use, and proper consideration of temporal and spatial scales. It was designed in order to allow for an accurate, consistent and transparent collection of damage and loss data. The tool took into consideration all the phases of damage and loss collection recording, storing, managing, maintaining an up-to-date documentation of the database, and performing queries to retrieve information.

The model was designed according to three main requirements:
- Flexibility and standardisation, to be adaptable to different societal sectors and their specific characteristics but creating a structure that allowed to collect information in a standardised fashion,
- Spatial and temporal characteristics of the information collected at the asset level, queried and filtered at different scales,
- Damage causality and dependency model features embracing the inter- and intra-connection of damages, within the same sector or due to the dependency of others, tracking the causality.

The three main features of the system functionality were the data collection process that eliminated any redundancy and inconsistency, the data storage, as a relational database to allow the retrieval of data through queries elaborated in advance to support a range of different purposes and multiple objectives, and the data management permitting efficient search performance of the prefigurated queries.

The LODE information system included a Dashboard i.e., a visualisation of the data queries results over a map. This Dashboard used the ArcGIS Online (AGOL) service and was demonstrated during the final workshop with stored data and real-time data openly available in the Internet.

3.1.8 FASTER PROJECT

FASTER or "First responder Advanced technologies for Safe and efficient Emergency Response" as its full title is, was a H2020 project under the H2020-SU-SEC-2018-2019-2020 call and the "SU-DRS02-2018-2019-2020 – Technologies for first responders" topic, with a duration of three years, from May 2019 till April 2022. The aim of the project was to deliver technologies for stakeholders who are engaged in the management of disasters, whether natural or man-made. These stakeholders consist of first responders, law enforcement agencies, volunteers and NGOs as well as HAZMAT teams, anti-terrorism units, civil protection agencies and other private or public organisations. In the case of a disaster various first responders' teams with different backgrounds and competencies might be needed to operate, a situation that might prove quite complicated, hinder situational awareness and a common operational picture from all practitioners and, in the end, delay response operations and the resolution of the crisis (CORDIS EU research results, n.d.).

To this direction, the objective of the project was to enhance first responders' capabilities to operate in harsh environments and to enhance communications among different teams, thus enhancing situational awareness, while at the same time protecting their health and physical condition during operations. The project delivered a variety of technological tools including unmanned vehicles, resilient communications and AR tools among others. A multi-disciplinary approach was followed, since first responders' organisations with different backgrounds participated in the project and significantly contributed to all the phases of technological development, from the design phase to the piloting and validation phase. This inclusion of operational agencies ensured that technologies are in line with what first responders require and that they do cover gaps and challenges which first responders face during emergency management.

Project Results

With is technological outcomes, the aim of the project was two-fold:

2. To provide first responders with increased situational awareness,
3. To increase their level of safety during operations (FASTER, n.d.).

In order to facilitate and enable a common operational picture the project developed the following technologies:

1. Mobile AR technologies for operational support

AR technology was developed for civil protection units with the aim of providing stakeholders with real time information deriving from other technologies of the project e.g., sensors and UxVs. Mobile phones and AR glasses were developed enabling real time acquisition of crucial information as well as filtering of this information aiming at the provision of targeted content to the user.

2. UAVs for the overall picture of the disaster site

The project made use of lightweight UAVs, which are equipped with cameras and can provide a clear picture of the disaster and the affected area. Unmanned vehicles have the capability of reaching specific areas, which are not easily accessible by first responders and transmit audio visual material. In addition, the UAVs of the project are equipped with AR see-through devices. Combined with 3D scene analysis and modelling algorithms, it becomes possible for the end users to extend their line of sight by making obstacles between the user and the vehicle partially transparent.

Additionally, the unmanned vehicles, either aerial or ground, will have the capability to be deployed and navigated without the use of controller devices, but only with body, head and hand gestures. This will free UAV and UGV operators as they will be able to stir and navigate the vehicles via gaze and head movements and hand gestures.

3. Robotic platform

A ground robotic vehicle was developed by the project, which is equipped with various sensors e.g., thermal and optical cameras and sensors that can detect dangerous CBRNe agents, as well as with a robotic arm that provides different capabilities. Moreover, it offers a takeoff / landing platform for drones, whereas, through the operation control console with its numerous visualisation capabilities, the operator can acquire a holistic picture of the disaster scene.

Regarding the increase of the level of safety, the project developed the following technologies, which target both first responders and K9 units:

1. Mission management and progress monitoring technologies

The most important aspect in disaster management is the effective coordination of response operations, especially in cases which require the concurrent deployment of different organisations. For that reason, the FASTER project developed a mobile application for the on-scene units, capitalising on the application already developed by the I-REACT project, which facilitates communications among different agencies, provides real time information to command-and-control centres and enables the management of different missions and the reporting of new incidents. Moreover, through the application, the geolocation of K9 units is available.

2. Smart textiles and wearable sensors

Sensors integrated in first responders' textiles were also developed under the framework of the FASTER project. These sensors are equipped within the uniforms and collect biometric data such as heart rate and body temperature. This information is transmitted, through a smartphone, to the command-and-control centre providing a near real time picture of the first responder's physical condition as well as his/her accurate position. Furthermore, with the use of AI, first responders' specific body movements can be translated and communicated to other practitioners on-site in the form of vibrations which follow the Morse code. Bluetooth Low Energy and IoT communications are used with the aim to resolve the issue of collapsed communications, which is very likely during disasters.

3. K9 behaviour recognition technologies

K9 units, that are highly used in disaster operations, can be equipped with wearable devices, developed in the context of FASTER, which, through DL models, can translate body movements to specific messages allowing operators in the command post to assess their condition and physical status as well as their exact position. Similar to the responders' sensors, the readings of the wearable devices are transmitted with the use of IoT communication protocols (FASTER, n.d.).

3.1.9 RESPOND-A PROJECT

The RESPOND-A was a H2020 project under the H2020-SU-SEC-2018-2019-2020 call and with a duration of three years, from June 2020 till May 2023. The RESPOND-A aimed at leveraging first responders' safety and efficiency by maximising situational awareness and enhancing their operational capabilities. Bringing together a variety of novel technologies, the project boosted timely safety assessment, risk mitigation, while ensuring a clear common operational picture and optimal operations management, even between different emergency units. It developed technologies based on 5G wireless communications, AR/VR or autonomous robots in order to optimise first responders' work. In the context of the project, first responders had the opportunity to test these technologies and see how efficiently they can be applied within the framework of diverse disaster scenarios. With these technological advances, first responders will be able to better predict and assess incidents and to safeguard themselves before, during and after disasters. Figure 16 depicts the generic concept diagram of the RESPOND-A implementation. (The Consortium of the RESPONDERS A Project. RESPONDERS A D2.2 System Specifications and Architecture)

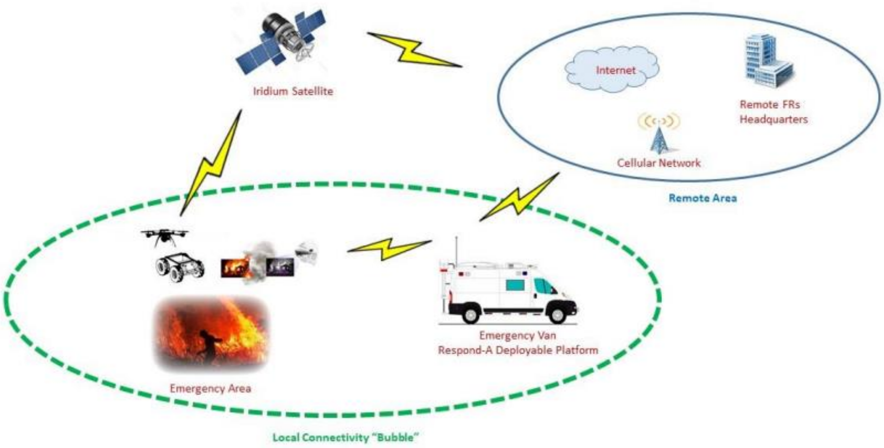


Figure 16: RESPOND-A Concept, Source: RESPOND-A D2.2

The RESPOND-A project had 9 objectives:

- Identification of first responders' situational awareness requirements and specificity of how the proposed mission-critical networks and applications reflected these requirements in cost-effective manner.
- The development and provision of first responders' equipment tools with continuous connectivity for protecting them against multiple unexpected dangers.
- The deployment and usage on demand of connected fleets of UAVs for improving personnel safety and ensuring seamless access to video and sensor data.
- The extracted knowledge and directions for first responders' training exercise with respect to the usability of the proposed tools and applications.
- The deployment on site, the positions of experimental testing and the performance of the real-world, validates the developed network-enabled equipment tools and applications using the training facilities.
- The execution of large-scale demonstration based on concrete application scenarios.
- The design and the establishment of novel practices for the interaction between First Responders and research centres.
- The dissemination and communication of the technological, conceptual and practical outcomes of the project for raising impact awareness for both first responders' organisations and the community, and exploit synergies with other EU projects.
- The exploitation strategy and the development of a business marketing plan for the potential commercial rollout of the RESPOND-A project results (RESPOND-A, n.d.).

Project Results

RESPOND-A focused in a five-pillar architectural structure to optimise first responders' work. The architectural layers are presented below:

1. PERCEPTION

Monitor data sources and collect the multi-disciplinary information that arrive in real time from:

- *the safety and biometric sensors in the vests of first responders*: A variety of sensors e.g., health, environmental, among others, embedded on FRs normal equipment, life jackets and helmets, collecting data and sending them to the mobile C&C center through the data logger, a device that manages and transmits data from the field to the van.
- *the localisation sensors for the personnel*: FRs and victims location tracked using GPS and Ultra-Wide Band (UWB) devices. The latter, utilising UAVs as anchors (or fixed points when UAV flight is not feasible), will be able to extract the human position even indoors, where the GPS signal is not available.
- *sensors placed on UAVs and tactical robots*: UAVs and UGVs will operate in the field, embedded specialised equipment and software for being integrated into the RESPOND-A ecosystem.
- *video streaming from 360^0 cameras*: The specific camera was lightweight and compact device, so it was attached to the drones, dronsters and robots (UxVs)
- *thermal cameras:* It was used either by a first responder or an Unmanned Vehicle to detect and sense objects or victims when visibility is limited (e.g., smoke, low light etc.).
- *AR devices:* first responders will use the AR application for enhancing their capabilities in the field, during operations. AR goggles, thermal cameras and smartphones/tablets running the AR client applications of Consortium partners will be utilised, communicating with the mobile CC centre platform.

2. PROCESSING

The phase of processing refers to the collection and processing of data, which are transmitted from the Network layer. The transmission was towards:

- The removal of redundant data to avoid network overload,
- The aggregation of large amounts of information to foster situational awareness and a common operational picture quickly with the aid of Multi-access Edge Computing (MEC),
- The fusion and comparison of the runtime information with patterns of previous incidents to discerned statistical trends for early warning,
- The formulation of path planning schemes for optimal UAVs/robots positioning with respect to responders' locations, and
- The articulation of information for recording knowledge of emergency events and response activities, including Electronic Health Records (EHRs) and Geographic Information System (GIS) databases.

3. NETWORK

The responders and Command Centres connectivity would be feasible via 5G portable telecommunications system with dynamically adjustable UAVs/drones network coverage umbrella. A UAV was connected to the 5G network and managed by the smart fleet management module flies around and sent video stream to the video platform in the van. The officers watched the video on the big screen and detected the Regions of Interest (ROI) (e.g., a building on fire). Also, services via real-time shared the video flows and data-rich multimedia content formed to be projected by any kind of devices, e.g., from responders' personal smartphones, tablets, laptops, to specialised AR glasses and 3D projectors.

4. COMPREHENSION

In the comprehension phase will be integrated all the collected/transferred/aggregated/processed information into a common ICT wireless system infrastructure in order to create the precise Situational Awareness and COP. All the intended applications and services of RESPOND-A are included in this layer, such as (i) the Command-and-Control Centre, (ii) AR module for overlaying real-time video streams with augmented data, (iii) medical support system, and (iv) Early Warning.

5. USER INTERFACE

The user interface layer will deliver the Situational Awareness COP through dedicated mobile applications, web applications and AR/haptic devices assisted by interactive processes, like gesture and context recognition. The intended interfaces will be dedicated to the Command and Control (The Consortium of the RESPOND A Project, 2021).

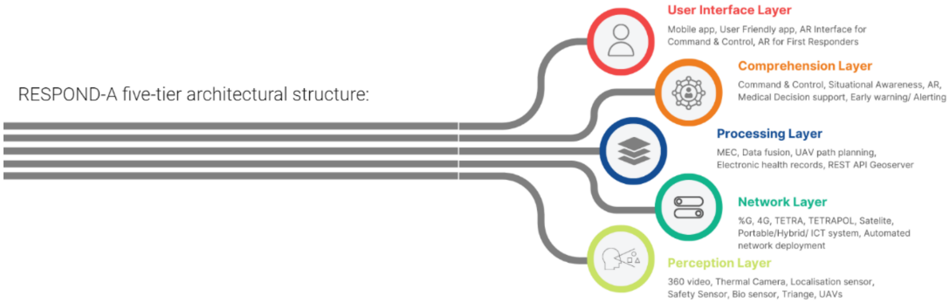


Figure 17: RESPOND-A five-tier architectural structure, Source: RESPOND-A

3.2 CORRELATION AND COMPLEMENTARITY OF PANTHEON WITH EXISTING INNOVATIONS

There is an apparent correlation and interconnection between the aforementioned projects and PANTHEON, both in terms of technologies and of the ultimate focus of the project, which is the overall enhancement of the capabilities of the society against natural and man-made disasters. In particular, vulnerable groups and the assessment of their capacity, in the face of high impact disasters, require a multi-stakeholder approach However, research also expands to other domains i.e., the development of technologies, which assist and facilitate the achievement of a common operational picture and situational awareness, especially in cases of emergencies that require cross-agency or cross-border collaboration. Moreover, technologies that enhance the capabilities of critical infrastructure operators in order to promptly address situations that disrupt normal operations and to timely exchange valid information with first responders and the community are of great significance.

Although the objectives might differ in comparison with PANTHEON, there are common grounds, correlations and space for the exchange of experience, expertise and knowledge, especially between the projects. Capitalising on the outcomes of past and present endeavours, PANTHEON can improve its approaches, optimise strategies and avoid potential pitfalls. For instance, the aforementioned Knowledge Platform of the Engage project (chapter 3.1.3), with its catalogue of solutions, can be leveraged by PANTHEON for the development of the community-based Digital Twin. In addition, the utilisation of newly developed technologies and innovative approaches is another area of interest. The role of technology in improving disaster risk assessment and response and in engaging the community as an active member in disaster management is specifically highlighted in research projects. PANTHEON will utilise this knowledge to add value to the innovations expected to be delivered by the end of the project.

Another crucial aspect showcased is the engagement of different stakeholders for a holistic approach regarding the management of crises and disasters. For instance, the LINKS project aims to bring together stakeholders such as first responders, public authorities, civil society organisations, and researchers across Europe. Similarly, PANTHEON aims to engage citizens, stakeholders, decision-makers, and communities in building disaster resilience. This shared focus on collaboration underscores the need for multi-sectoral involvement and cooperation.

Overall, the following aspects recap common grounds and complementarity between PANTHEON and similar identified projects, both in terms of technical aspects and of challenges and gaps to be addressed:

- **Risk assessment and management:** Societal resilience involves identifying and assessing potential risks and vulnerabilities within a community or society. This includes understanding the impacts of different hazards and developing strategies to mitigate or manage those risks effectively.
- **Social cohesion and community engagement:** Building strong social networks, fostering trust and promoting community participation are crucial for enhancing societal resilience. Engaging diverse stakeholders and empowering local communities can contribute to better preparedness, response and recovery.
- **Adaptive capacity and flexibility:** Societal resilience requires the ability to adapt and respond to changing circumstances. This includes developing flexible policies, systems, and infrastructures that can withstand shocks, recover quickly, and promote sustainable development.
- **Multi-sectoral collaboration:** Collaboration and coordination among various sectors, including government agencies, non-governmental organizations, businesses, academia and community-based organisations are essential for achieving societal resilience. These partnerships can facilitate resource sharing, knowledge exchange, and coordinated responses in times of crisis.
- **Capacity building and education:** Investing in education, training, and capacity-building initiatives at individual, community and institutional levels can enhance resilience. This includes promoting disaster preparedness, teaching life skills, and providing resources for sustainable livelihoods.
- **Information sharing and communication:** Effective communication systems, early warning mechanisms and public awareness campaigns play a crucial role in enhancing societal resilience. Access to accurate and timely information enables individuals and communities to make informed decisions and take appropriate actions during emergencies.
- **Data utilisation for risk assessment and decision making:** Multi-source data, including remote and in-situ, social networks and historical data are efficient tools for the development of systems for risk assessment and information dissemination. Moreover, the experience from past projects e.g., AIDERS, could assist in the identification of crucial, for first responders, data, and of the "when", "where" and "how" these data can be utilised for an optimised deployment swarm UAVS. PANTHEON combines IoT infrastructure and multi-source data to assess risks, vulnerabilities, and capacities. The common emphasis on data highlights the importance of evidence-based approaches in disaster resilience.
- **Utilisation of digital twin technologies:** Digital twins have many forms. DTs first emerged in manufacturing, where their role is acting as a detailed digital model that can be duplicated in physical copies. There, the economic benefits are reaped from detailed planning. In construction, DT techniques provide similar benefits, with the addition that the information about the physical landscape of the building can be brought in the planning. Facility management, including building maintenance and asset management, also gains economic benefits from DT techniques, but needs

periodic updating of DTs. City DTs bring in even more complexity in the form of both technical issues, such as the integration of GIS and BIM, and human factors, such as that it becomes unclear what purpose do the city DTs ultimately serve (Ville V. Lehtola, 2022). Cities never stop changing, and therefore the DT of a city. The overall challenge and target of PANTHEON is to deploy technologies in order to build and maintain a SCDT. Digital twin technologies enable the analysis and monitoring of an entity, e.g., of a critical infrastructure. The digital twin provides the mirror image of the entity and thus, provides the capability of monitoring its operational functionality and behaviour, allowing for early detection of disruptions and, consequently, for a timely response to and recovery from emergency situations. As a result, prevention of disruptive circumstances is significantly enhanced.

- **AI Social intelligence:** Social intelligence in the context of artificial intelligence refers to the capability of AI systems to understand, respond to and exhibit behaviour that is in line with the social and emotional dynamics of human beings. The development of AI with social intelligence in the PANTHEON project has numerous potential goals, including, but not limited to, understanding and responding to emotion, recognition of social cues and norms, adaptability and communication skills.

- **Unsupervised learning:** It is a type of ML that analyses a stream of data, finds patterns and makes predictions without any other guidance. It uses algorithmic approaches to analyse and cluster input data that has not been labelled, classified or characterised in advance. This implementation is a key point for AI training in the PANTHEON project bearing in mind the amount of input data processed and the DSS.

CONCLUSIONS

Technology provides efficient ways to combat and manage disasters and crises. However, as a first step it is important to align technological innovations and products with end users' needs and requirements. The European Commission has thoroughly examined this issue and came up with significant results, which need to be addressed by disaster management stakeholders. Moreover, EU-funded research projects have seriously taken into consideration the aforementioned lack of correlation between end user needs and technological providers' interests, aiming at bridging this gap.

PANTHEON, as a project which targets the society and aims to deliver technologies that will engulf all disaster-related stakeholders, builds upon the experience gained from past and ongoing endeavours and orients its technological development towards innovations which will facilitate and enhance operational capacity and capabilities. Among the innovations that are expected to be delivered by the project are smart city digital technologies, AI-based technologies, DSS and assets management systems as well as risk monitoring technologies. These innovations are closely related to the outcomes of large networking projects e.g., FIRE-IN and MEDEA, as they address recognised first responders' capability challenges and needs. Based on an extensive literature review, this Deliverable provides significant information to the reader, which include, inter alia, field applications of these technologies, identified gaps and developments expected to take place during the lifetime of PANTHEON.

Another important aspect examined by this document is the identification of research projects, that have produced significant outcomes which are of close relation to PANTHEON. The majority of these projects is community-oriented and provides solutions that address not only first responders but also society. Furthermore, projects which target CI operators, providing technologies that will allow improved management of disruptions are included. As CIs are becoming increasingly interconnected, the impact of crises and disasters is multiplied. PANTHEON will leverage, among others, the outcomes of these projects and will capitalise knowledge, experience, good practices and lessons learnt in order to successfully deliver the expected outcomes and fulfill its objectives.

Finally, compliance and complementarity of PANTHEON with past and ongoing research projects has been highlighted in this document. A correlation between the results of these projects and the expected future outcomes of PANTHEON has been conducted, thus providing insights on how existing knowledge will be utilised for further development under the framework of PANTHEON.

REFERENCES

(n.d.). Retrieved from PRECINCT: https://www.precinct.info/

(n.d.). Retrieved 7 17, 2023, from FIRE-IN: https://www.fire-in.eu/

(n.d.). Retrieved 7 19, 2023, from LINKS Strengthening links between technologies and society for European disaster resilience: https://links-project.eu/#

(n.d.). Retrieved from EC CORDIS: https://cordis.europa.eu/project/id/101019707

(n.d.). Retrieved from RESPOND-A: https://respond-a-project.eu/

(n.d.). Retrieved from LODE Loss Data Enhancement for DRR & CCA management: https://www.lodeproject.polimi.it/

(n.d.). Retrieved from MEDEA: https://www.medea-project.eu/

Abdeen, F. N. (2022). City Digital Twin Concepts: A Vision for Community Participation. *The 3rd Built Environment Research Forum.* doi:https://doi.org/10.3390/environsciproc2021012019

Alghamdi, M. (2023). Smart city urban planning using an evolutionary deep learning model. *Soft Computing*. doi:10.1007/s00500-023-08219-4

Akay, A., Wing, M., & Sivrikaya, F. (2012). A GIS-based decision support system for determining the shortest and safest route to forest fires: A case study in Mediterranean Region of Turkey. *Environmental Monitoring and Assessment*.

Arthur de M. Del Esposte, E. F. (2019). Design and evaluation of a scalable smart city software platform with large-scale simulations. *Future Generation Computer Systems*. doi:https://doi.org/10.1016/j.future.2018.10.026

CORDIS EU research results. (n.d.). Retrieved 7 17, 2023, from https://cordis.europa.eu/project/id/833507

CORDIS EU research results. (2022, September 22).

Dembski, F. W. (2020). Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. *Sustainability*. doi:https://doi.org/10.3390/su12062307

Deng, T. Z.-J. (2021). A systematic review of a digital twin city: A new pattern of urban governance toward smart cities. *Journal of Management Science and Engineering*. doi:https://doi.org/10.1016/j.jmse.2021.03.003

Deren, L. W. (2021). Smart city based on digital twins. *Springer*. doi:https://doi.org/10.1007/s43762-021-00005-y

ENGAGE. (n.d.). Retrieved June 29, 2023, from https://www.project-engage.eu/

Eom, S. &. (2006). A survey of decision support system applications (1995–2001). *Journal of the Operational Research Society*. doi:https://doi.org/10.1057/palgrave.jors.2602140

Eom, S. K. (2017). A survey of decision support system applications (1995–2001). *Journal of the Operational Research Society*. doi:https://doi.org/10.1057/palgrave.jors.2602140

Eom, S. K. (2017). A survey of decision support system applications (1995–2001). *Journal of the Operational Research Society*. doi:https://doi.org/10.1057/palgrave.jors.2602140

European Commission DG HOME. (2022). *EU Security Market Study.*

Fahim Ullah, S. Q.-T. (2021). Risk management in sustainable smart cities governance: A TOE framework. *ELSEVIER*.

Fan, C. Z. (2021). Disaster City Digital Twin: A vision for integrating artificial and human intelligence for disaster management. *International Journal of Information Management*. doi:https://doi.org/10.1016/j.ijinfomgt.2019.102049

FASTER. (n.d.). Retrieved 7 17, 2023, from https://www.faster-project.eu/tech/

Ford, D. N. (2020). Smart Cities with Digital Twin Systems for Disaster Management. *Journal of Management in Engineering*. doi:https://doi.org/10.1061/(ASCE)ME.1943-5479.0000779

Francisco, A. M. (2020). Smart City Digital Twin–Enabled Energy Management: Toward Real-Time Urban Building Energy Benchmarking. *Journal of Management in Engineering*. doi:https://doi.org/10.1061/(ASCE)ME.1943-5479.0000741

H.M.K.K.M.B. Herath, M. M. (2022). Adoption of artificial intelligence in smart cities: A comprehensive review. *International Journal of Information Management Data Insights*. doi:https://doi.org/10.1016/j.jjimei.2022.100076

Huang, W. Z. (2022). Development and application of digital twin technology for integrated regional energy systems in smart cities. *Sustainable Computing: Informatics and Systems*. doi:https://doi.org/10.1016/j.suscom.2022.100781

Irum Hafeez Sodhar, A. H. (2020). Natural Language Processing: Applications, Techniques and Challenges. *ADVANCES IN Computer Science*. doi:10.22271/ed.book.784-

Ishak, W., Ku-Mahamud, K., & Morwawi, N. (2011). Conceptual model of intelligent decision support system based on naturalistic decision theory for reservoir operation during emergency situation. *International Journal of Civil & Environmental Engineering*.

Jung, D. T. (2020). Conceptual framework of an intelligent decision support system for smart city disaster management. *Applied Sciences*.

Kotzanikolaou, P. M. (2011). Interdependencies between critical infrastructures: Analyzing the risk of cascading effects. *Critical Information Infrastructure Security: 6th International Workshop, CRITIS 2011.* Lucerne, Switzerland: Springer Berlin Heidelberg.

Lars Ruthotto, E. H. (2021). An Introduction to Deep Generative Modeling. *Special Issue: Scientific Machine Learning - Part II*. doi: https://doi.org/10.1002/gamm.202100008

LINKS, Strengthening links between technologies and society for European disaster resilience. (n.d.). Retrieved 7 19, 2023, from https://links-project.eu/#

Luong Nguyen, M. S. (n.d.). *Digital Twin for IoT Environments: a Testing and Simulation Tool.*

Major, P. L. (2021). The Use of a Data-Driven Digital Twin of a Smart City: A Case Study of Ålesund, Norway. *IEEE Instrumentation & Measurement Magazine*. doi:https://doi.org/10.1109/MIM.2021.9549127

Md Eshrat E., A. A. (2023). Integration of IoT-Enabled Technologies and Artificial Intelligence (AI) for Smart City Scenario: Recent Advancements and Future Trends. *Sensors*. doi:https://doi.org/10.3390/s23115206

Mohammadi, N. &. (2021). Thinking fast and slow in disaster decision-making with Smart City Digital Twins. *Nature Computational Science*. doi:https://doi.org/10.1038/s43588-021-00174-0

Muhammad Saad, T. R. (2018). CYBER SECURITY AND INTERNET OF THINGS. *Pakistan Journal of Engineering, Technology & Science*. doi:http://dx.doi.org/10.22555/pjets.v7i1.2084

Rajabifard, A., Thompson, R., & Chen, Y. (2015). An intelligent disaster decision support system for increasing the sustainability of transport networks. *Natural Resources Forum*.

Ruohomaki, T. A. (2018). Smart City Platform Enabling Digital Twin. *2018 International Conference on Intelligent Systems (IS).* doi:https://doi.org/10.1109/IS.2018.8710517

S. Mahdavi-Hezavehi, P. A. (2017). Chapter 3 - A Classification Framework of Uncertainty in Architecture-Based Self-Adaptive Systems With Multiple Quality Requirements. *Managing Trade-offs in Adaptable Software Architectures*. doi:http://dx.doi.org/10.1016/B978-0-12-802855-1.00003-4

Saeed Nosratabadi, A. M. (2010). State of the Art Survey of Deep Learning and Machine Learning Models for Smart Cities and Urban Sustainability. doi:https://doi.org/10.1007/978-3-030-36841-8_22

Sarker, I. H. (2021). Machine Learning: AlgorithmsReal, World Applications and Research. *SN Computer Science*.

Schleicher, J. M. (2016). A holistic, interdisciplinary decision support system for sustainable smart city design. *Smart Cities: First International Conference, Smart-CT 2016, Málaga, Spain.* Springer International Publishing.

Simões-Marques, M., & Figueira, J. (2018). How Can AI Help Reduce the Burden of Disaster Management Decision-Making? *International Conference on Applied Human Factors and Ergonomics; Springer: Berlin/Heidelberg, Germany, 2018.* Springer: Berlin/Heidelberg, Germany, 2018.

Soroudi, M. G. (2023). A Serious Game Conceptual Approach to PRotect Critical Infrastructure Resilience in Smart Cities. Dublin, Ireland.

Sprague, R. (1980). A Framework for the Development of Decision Support Systems. *MIS Quarterly*. doi:https://doi.org/10.2307/248957

Stergiopoulos, G. e. (2016). Time-based critical infrastructure dependency analysis for large-scale and cross-sectoral failures. *International Journal of Critical Infrastructure Protection*.

The Consortium of the AIDERS Project. (n.d.). *AIDERS D5.3 "AI toolkit user manual".*

The Consortium of the AIDERS Project. (n.d.). *AIDERS D6.11 "Layman's project report".*

The Consortium of the Builders Project. (2018). *Builders D2.4 "Catalogue of Tools, Technologies and Media Opportunities for Disaster Management".*

The Consortium of the Builders Project. (2019). *BUILDERS D5.2 "Innovation Policy Recommendtions".*

The Consortium of the Builders Project. (2019). *Builders D6.6 "Stakeholders Validation of Research Findings and Co-creation of Innovations".*

The Consortium of the ENGAGE Project. (2021). *Deliverable 1.3 - Communication, Social Media and Societal Resilience Among Citizens.*

The Consortium of the Engage Project. (2021). *Deliverable 2.2 - Formal solutions to improve societal resilience.*

The Consortium of the FIRE-IN Project. (2020). *D3.3. Results of the Requests for ideas: mapping RTOs and industry potential, response and trends related to FIRE-IN CCC/FCCCs #2.*

The Consortium of the FIRE-IN Project. (2022). *D3.4 "Results of the Request for Ideas: mapping RTOs and Industry potential, response and trends related to Fire-IN CCC/FCCCs #3.*

The Consortium of the LINKS Project. (2020). *LINKS D4.1 "Knowledge Base".* Retrieved from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://links-project.eu/wp-content/uploads/2021/05/LINKS_D4.1_Disaster-Community-Technologies_V2.0_compressed.pdf?fbclid=IwAR3px3ElgTr9GKJd52I4y0hJ8uuy2B_XavsGB28v0ASxWYbu2bF2UiC3URM

The Consortium of the LINKS Project. (2021). *LINKS D7.1 "Report about the needs and potentials of LINKS Community Center.*

The Consortium of the LODE Project. (2019). *LODE D2.2 "Good practices and challenges of current loss and damage data management".* Retrieved from https://www.lodeproject.polimi.it/events/

The Consortium of the LODE Project. (2021). *LODE D5.3 "Layman Report of the Lode project.* Retrieved from https://www.lodeproject.polimi.it/events/

The Consortium of the PANTHEON Project. (2023). *PANTHEON D2.1 "Community based DRM analysis and regional ecosystem".*

The Consortium of the PANTHEON Project. (2023). *PANTHEON D2.2 "Multi-Hazards/risk data and assessment report".*

The Consortium of the PRECINCT Project. (2023, July). *Promotional material & newsletters, PRECINCT Newsletter 6.* Retrieved from https://www.precinct.info/en/publications/promotional-material-newsletters/

The Consortium of the RESPOND A Project. (2021). *RESPOND A D2.2 "System Specifications and Architecture".* Retrieved from https://zenodo.org/record/6976841

The Consortium of the RiskPACC Project. (2022). *RiskPACC D4.1 "Report to WP3 on prototype co-creation methodology".*

The Consortium of the RiskPACC Project. (2023). *RiskPACC D5.1 "Completion of crowdsourcing solution development to the different case study requirements".*

The Consortium of the RIskPACC Project. (2023). *RIskPACC D5.2 "Completion of sentiment analysis toolbox to measure the RPAG".*

The Consortium of the RIskPACC Project. (2023). *RIskPACC D5.3 "Completion of adaptation of VGI mapping tool to close the RPAG".*

The European Commission. (n.d.). *Social media-driven disaster risk management.* Retrieved June 28, 2023

Turban, E., Cameron Fisher, J., & Altman, S. (1988). Decision support systems in academic administration. *Journal of Educational Administration*.

Ville V. Lehtola, M. K.-P. (2022). Digital twin of a city: Review of technology serving city needs. *International Journal of Applied Earth Observation and Geoinformation*. doi:https://doi.org/10.1016/j.jag.2022.102915

White, G. Z. (2021). A digital twin smart city for citizen feedback. *Cities*. doi: https://doi.org/10.1016/j.cities.2020.103064

Wolf, K. D. (2022). Towards a digital twin for supporting multi-agency incident management in a smart city. *Nature*. doi:https://doi.org/10.1038/s41598-022-20178-8

Xia, H. L. (2022). Study on city digital twin technologies for sustainable smart city design: A review and bibliometric analysis of geographic information system and building information modeling integration. *Sustainable Cities and Society*. doi:https://doi.org/10.1016/j.scs.2022.104009

Yossef Ravid, B. &.-G. (2023). The Social Digital Twin:The Social Turn in the Field of Smart Cities. *Environment and Planning B: Urban Analytics and City Science,*. doi:https://doi.org/10.1177/23998083221137079

Zhenchang Xia, S. X. (2021). Deep Reinforcement Learning for Smart City Communication Networks. *IEEE Transactions on Industrial Informatics.* doi: 10.1109/TII.2020.3006199