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Smart and Sustainable Cities with the Use of Digital Twin Platforms for Enhanced Community Disaster Resilience

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Abstract
The increasing complexity and interconnectivity of urban systems necessitate new approaches to managing disasters, promoting sustainability, and enhancing resilience. This paper explores how Smart and Sustainable Cities can leverage Digital Twin (DT) platforms to enhance community disaster resilience through data-driven decision-making, multi-level coordination, and citizen participation. The study integrates engineering design and the European Union's policy perspectives, building upon research outcomes from key Horizon Europe research and innovation projects such as PANTHEON, RESCUER, and STRATEGY. A multi-city framework is proposed to demonstrate how Digital Twin technologies can be deployed across different urban contexts, enabling cross-city cooperation, predictive analytics, and sustainable recovery planning. The paper concludes with recommendations for standardisation, governance, and implementation pathways aligned with European resilience objectives.

Keywords
smart cities, sustainability, disaster resilience, digital twin, EU policy, Horizon Europe, standardisation

1. Introduction

Cities across Europe are facing increasingly severe and interconnected challenges due to climate change, rapid urbanisation, and complex infrastructure dependencies. Smart and Sustainable Cities (SSCs) aim to combine environmental responsibility with technological advancement to improve the quality of life and resilience of urban populations.

Digital Twin (DT) technology provides a real-time digital representation of physical systems and processes, enabling simulation, prediction, and decision support for city operations and disaster management. This paper investigates the potential of Digital Twin platforms in multi-city networks to strengthen disaster resilience through shared data, standardisation, and community participation, referencing European policy frameworks and the EU's main funding program for research and innovation (HORIZON) [1], which delivered impactful projects such as RESCUER (H2020-EU.3.7; SU-DRS02) [2] and PANTHEON (HORIZON.2.3 - Civil Security for Society; HORIZON-CL3-2021-DRS-01-01) [3]. This study provides a literature review examining existing research on European Union policies and standards, highlighting developments and challenges identified by relevant research projects.

2. Policy and Technological Background

2.1. European Union

The European Union has established strategic frameworks for digital transformation and disaster resilience through programmes such as Horizon Europe, Digital Europe, and the Civil Security for Society cluster. Policies like the Critical Entities Resilience Directive (EU 2022/2557) emphasise risk assessment, cross-sectoral coordination, and data-driven prevention. From a technological perspective, Digital Twins integrate IoT data, Earth Observation (EO), artificial intelligence (AI), and simulation to monitor and predict system behaviour. The EU Critical Entities Resilience (CER) Directive establishes requirements to strengthen the resilience of critical infrastructure across member states. It mandates that operators of essential services and critical entities in smart cities identify risks, implement preventive measures, and ensure continuity during disasters [4].

By emphasising both digital and physical security, the directive supports the reliable functioning of interconnected urban systems, a cornerstone of smart city development. Regular risk assessments, incident reporting, and resilience planning align with sustainability goals by minimising disruption to

essential services and reducing socio-economic impacts. In this way, the CER Directive contributes directly to building smart, sustainable, and disaster-resilient urban environments

EU-funded projects such as PANTHEON demonstrate community-based digital ecosystems for disaster management, while RESCUER enhances operational resilience for first responders, providing critical input for DT-based situational awareness.

Moreover, the EU NIS2 Directive (Directive (EU) 2022/2555) establishes a comprehensive legal framework aimed at enhancing the cybersecurity and resilience of network and information systems across the Union. It extends its scope to include a broader range of sectors and entities, emphasising the need for robust cybersecurity measures to safeguard critical infrastructure [5]. Aligned with the objectives of the NIS2 Directive, digital twin technology supports the implementation of stringent cybersecurity measures. It aids in compliance with requirements such as risk assessment, incident reporting, and the establishment of security policies. Furthermore, digital twins contribute to enhancing situational awareness and coordination among stakeholders, which are essential for effective cybersecurity governance as outlined in the directive.

In summary, the integration of digital twin platforms within the framework of the NIS2 Directive represents a strategic approach to fortifying the cybersecurity and resilience of critical infrastructure. By leveraging advanced simulation and monitoring capabilities, digital twins enable entities to meet the directive's requirements and enhance their preparedness against cyber threats.

2.2. Digital Twin Platforms

Digital twin platforms are advanced computational frameworks that create virtual replicas of physical systems, processes, or assets. They integrate real-time data from sensors, IoT devices, and other monitoring tools to simulate, analyse, and predict the behaviour of their physical counterparts. These platforms leverage technologies such as cloud computing, edge computing, AI, and machine learning to enable continuous optimisation and decision support. In smart cities, digital twins support infrastructure management, disaster resilience, and sustainability by allowing scenario testing, predictive maintenance, and performance monitoring [6]. Their ability to bridge the physical and digital worlds makes them essential for modern urban planning, critical infrastructure management, and policy compliance.

The European Union has initiated several policies and programs to promote the development and deployment of digital twin platforms, particularly within the context of smart and sustainable cities. Key initiatives include:

- EU Local Digital Twins Toolbox [7]: This collection of advanced, reusable tools, reference architectures, open standards, and technical specifications is designed to assist local communities and cities in creating Artificial Intelligence (AI)-based local digital twins. These digital twins can evaluate different scenarios and cases, helping cities make better decisions in real-time, such as managing traffic flow or responding to emergencies;
- CitiVERSE [8]: A digital environment that allows citizens to explore their city and see how different changes might affect it using advanced technologies like virtual and augmented reality. Citizens can test new plans for roads, parks, or buildings and see how they might impact traffic, pollution, or even the way people feel about their neighbourhood;
- European Digital Twin of the Ocean (DTO) [9]: This initiative aims to create a digital model of the ocean to support evidence-based decision-making for marine and maritime policies. The DTO will provide a comprehensive and integrated view of the ocean, enabling better management of marine resources and ecosystems;
- Virtual Human Twins Initiative [10]: Focused on health and care, this initiative supports the development of virtual human twins—digital representations of human health or disease states. These models can be used for personalised medicine, clinical trials, and surgical planning, among other applications.

These initiatives reflect the EU's commitment to leveraging digital twin technologies to enhance urban resilience, sustainability, and citizen engagement.

3. Multi-City Digital Twin Framework

A digital twin smart city builds on a number of layers of information in the city. Gary White, Anna Zink, Lara Codecà, Siobhán Clarke, in their work entitled "A Digital Twin Smart City for Citizen Feedback" [11], suggested a six-layer model as shown in Figure 1 below. The first five layers build on top of each other, adding more information about the terrain, buildings, infrastructure, mobility and Internet of Things (IoT) devices in the city. The Digital Layer/Smart City is used to collect data from the city, which it can then pass to the Virtual Layer/Digital Twin. The Digital Twin uses the data generated in the smart city to perform additional simulations about mobility optimisation, building placement or the design of renewable energy, such as offshore wind turbines. This information is then fed back through the layers of the model, where it is implemented in the physical world. The proposed framework expands beyond individual city applications to a multi-city Digital Twin ecosystem.

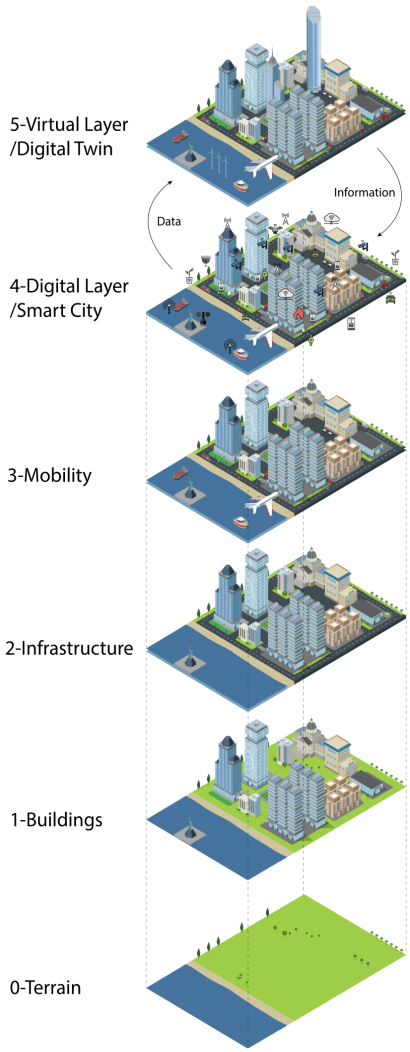

Fig. 1. Layers required to develop a Digital Twin Smart City [11]

The current paper considers that the fundamental framework expands beyond individual city applications to a multi-city Digital Twin ecosystem. Therefore, it could consist of five interconnected layers:

- Data Layer: Collects and harmonises data from IoT sensors, Unmanned Aerial Vehicles (UAVs), and Earth Observation (EO) platforms across multiple cities;
- Integration Layer: Ensures interoperability and compliance with open data standards (CEN/ISO, INSPIRE Directive [12]);
- Simulation and Modelling Layer: Provides predictive analytics, hazard simulations, and cross-border risk assessment;

- Decision Support Layer: Offers policymakers and responders visualisation dashboards, early warnings, and performance indicators;
- Community Layer: Facilitates citizen engagement, participatory planning, and feedback loops through mobile applications and training platforms.

4. Implementation and Case Studies

4.1. Case Studies

The Horizon Europe project PANTHEON (2023-2025, Grant agreement ID: 101074008, Topic: HORIZON-CL3-2021-DRS-01-01 - Improved understanding of risk exposure and its public awareness in areas exposed to multi-hazards), demonstrates how Digital Twins can operate as dynamic, community-based tools for urban resilience. Pilots across multiple European cities focus on integrating IoT sensor data, UAV imagery and social media analytics to support early detection and situational awareness.

The Project included and implemented a verification process of the platform suggested, which took place in several phases, e.g. Functional Testing, Security Testing, Compatibility Testing, Usability Testing, Regression Testing, Performance Testing, Compliance Verification (ensure the software platform complies with relevant standards, regulations, and industry best practices, i.e. IEEE 1730.2., 2022), Feedback Collection and Iteration (gather feedback from stakeholders, including end-users, developers, and testers, and use it to iterate on the software platform to address any identified issues or areas for improvement. The feedback will be collected and registered in an issue tracking mechanism (as Jira64), and Final Verification and Approval [3].

RESCUER (2021-2024, Grant agreement ID: 101021836, Topic: SU-DRS02-2018-2019-2020 - Technologies for first responders), complements this approach by providing cognitive and communication tools to first responders (SU-DRS02-2018-2019-2020 - Technologies for first responders) [4], while STRATEGY [12], project under the Grant Agreement Number: 883520, Topic: SU-DRS03-2018-2019-2020 – Pre-normative research and demonstration for disaster-resilient societies (2020-2023), focused on standardisation for interoperability in cross-border crisis management operations.

Moreover, the RESCUER project developed a toolkit offering sense augmentation through enhanced sensorial input, precise and infrastructure less self-positioning, and cognitive support and multi-sense augmented reality interfaces, improving their focus and capability to utilise information and robust ad hoc intra-team communications for both verbal and data exchanges. Lightweight and non-obtrusive devices and sensors are used to boost human sensing and operational capabilities [4].

The EU-funded STRATEGY project [13] developed a pan-European framework of pre-standardisation activities for systems, solutions and procedures in the form of two CEN CENELEC Technical Specifications and eleven CEN CENELEC Workshop Agreements (CWAs) [14], including the following ones,

- CWA 18005: 2023Requirements and recommendations for social media early warning messages in crisis and disaster management
- CWA 18013:2023 Collaborative emergency response - Common addressing format and emergency identification protocol
- CWA 18019:2023 Specifications for Digital Scenarios for Crisis Management Exercises
- CWA 18022:2023 Exchanging of building and infrastructure damage information with Common Alerting Protocol
- CWA 18023:2023 International and interinstitutional crisis and disaster management - Guideline for the mapping of terminology and icons

STRATEGY addressed crisis management, validated by sustainable tests and evaluation frameworks that can improve the crisis management and disaster resilience capabilities. Specifically, the project streamlined and validated technical and organisational interoperability in a fully transboundary configuration through the implementation of use cases involving CEN CENELEC and National Standardisation Bodies, such as Austrian Standards Institute (ASI), Romanian Standards Association (ASRO), Finnish Standards (SFS), Swedish Institute for Standards (SIS) and Spanish Association for Standardisation (UNE).

The aforementioned projects, among others, offer a practical roadmap for scaling DT solutions to regional and national levels, fostering collaboration between stakeholders such as local authorities, industry, and research organisations.

4.2. Recommendations and policy implications

The convergence of sustainability goals, data innovation, and policy integration makes Digital Twin technology a cornerstone for future Smart Cities. Challenges include the fragmentation of standards, unequal access to technology among municipalities, and privacy/security considerations. To achieve long-term success, governance mechanisms must support inter-city cooperation, transparent data exchange, and sustainable funding. The adoption of open standards and alignment with EU directives are crucial to ensure replicability and interoperability across borders.

The following five pillars could be of great support to efforts related to the enhancement of disaster resilience with the use of digital twin platforms to remain smart and sustainable cities:

- Standardisation: Encourage harmonised EU-wide standards for DT data formats, communications, and simulations under CEN and ISO frameworks;
- Governance: Establish cross-city coordination mechanisms and integrate DT systems into national disaster resilience strategies;
- Capacity Building: Support training programs for local authorities, first responders, and citizens on DT use for preparedness and response;
- Sustainability: Promote energy-efficient DT operations and long-term maintenance strategies;
- Funding: Expand access to Horizon Europe and Digital Europe funds for small and medium-sized municipalities to deploy DT solutions.

4.3. Standards Alignment

The deployment of Digital Twin platforms for Smart and Sustainable Cities should align with international and European standardisation efforts that ensure interoperability, security, and sustainability [6]. Relevant frameworks include ISO 37120, ISO 37122, and ISO 37123 on Sustainable Cities and Communities, which define indicators for city services, smart city performance, and resilience [15]; ISO/IEC 30182:2017 (Smart city concept model) and ISO/IEC 30146:2019 (Assessment of smart city ICT infrastructure) [15]; and ISO 14001 and ISO 22301 for environmental management and business continuity, respectively [6]. From the European perspective, CEN/TC 465 and CENELEC TC 278 develop standards supporting Smart Cities interoperability and intelligent transport [14]. Furthermore, CWAs such as CWA 17381:2019 (City Resilience Development – Operational Guidance) and CWA 17300:2018 (Mapping of Key Performance Indicators for Smart Cities) provide practical frameworks for resilience assessment and implementation [14]. The IEC Smart Cities Systems Committee (SyC) [16] also provides guidance for integrating cyber-physical systems and IoT architectures within urban infrastructures. Collectively, these standards promote a common technical and governance language, enabling harmonised Digital Twin development and cross-city collaboration across Europe.

4.4. Conclusion and Way forward

Smart and Sustainable Cities equipped with Digital Twin platforms represent a transformative step toward a resilient and sustainable Europe. By linking data, technology, and community engagement, these systems enable proactive disaster management and informed decision-making. The multi-city approach enhances scalability and mutual learning, turning data into actionable intelligence. Projects like RESCUER [2] and PANTHEON [3] demonstrate that combining engineering innovation with policy support can yield tangible benefits for citizens and the environment. Future efforts should focus on governance frameworks, standardisation, and international collaboration to ensure digital resilience across Europe.

The Horizon Europe - Work Programme 2025 - 6. Civil Security for Society, Destination - Disaster-Resilient Society for Europe and its topics of a) HORIZON-CL3-2025-01-DRS-01: “Open topic on citizen and regional and/or local authorities' engagement in enhanced disaster risk awareness, including education, and preparedness”, b) HORIZON-CL3-2025-01-DRS-02: “Open topic on Improving disaster risk management and governance to ensure self-sufficiency and sustainability of operations in support of enhanced resilience”, c) HORIZON-CL3-2025-01-DRS-03: “Open topic on testing / validating tools, technologies and data used in cross-border prevention, preparedness and responses to climate extreme and geological events and chemical, biological or radiological emergency threats”, and d) HORIZON-CL3-

2025-01-DRS-04: "Advancing autonomous systems and robotics for high-risk disaster response, strengthening disaster resilience in conflict-afflicted crisis zones", are expected to give very important results through the consortia that will work on and the projects that will be financed for the above purposes. Last but not least, ethical dilemmas and privacy aspects are crucial and should be investigated alongside technological and digital advancements because emerging technologies, such as AI, cloud and edge computing, and autonomous vehicles, create complex issues related to data security, privacy, discrimination, and autonomy. In our interconnected and interdependent world, these issues are not secondary but are fundamental to developing and deploying technology responsibly to benefit society and mitigate harm. Interdisciplinary working groups setting up in Horizon consortia and Standardisation Technical Committees are enablers for dealing efficiently with such complexities.

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