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D8.1-GIS Based Early Warning and Digital Twin Platform functional requirements

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym / Abbreviation	Meaning / Full text
AI	Artificial Intelligence
CC	Climate change
CCLL	Coastal City Living Lab
CIs	Critical Infrastructure
DMP	Data Management Plan
DRMKC	Disaster Risk Management Knowledge Center
DT	Digital Twin
DTM	Digital Terrain Model
EBA	Ecosystem-Based Approach
ECMWF	European Centre For Medium-Range Weather Forecasts
EFAS	European Flood Awareness System
ESA	European Space Agency
EWSS	Early Warning Support System
GIS	Geographic Information System
HHAP	Heat Health Action Plan
ICT	Information and Communications Technology
IOT	Internet Of Things
IR	Implementing Rules
IT	Information Technology
RPO	Research Performing Organisation
SIP	Score ICT Platform
SLR	Sea Level Rise
WP	Work Project

BACKGROUND: ABOUT THE SCORE PROJECT

The intensification of extreme weather events, coastal erosion and sea-level rise are significant challenges to be urgently addressed by European coastal cities. The science behind these disruptive phenomena is complex, and advancing climate resilience requires progress in data acquisition, forecasting, and understanding the potential risks and impacts of real-scenario interventions. The Ecosystem-Based Approach (EBA) supported by smart technologies has potential to increase climate resilience of European coastal cities; however, it is not yet adequately understood and coordinated at European level.

SCORE is a four-year EU-funded project aiming to increase climate resilience in European coastal cities. SCORE outlines a co-creation strategy, developed via a network of 10 coastal city 'living labs' (CCLLs), to rapidly, equitably and sustainably enhance coastal city climate resilience through EBAs and sophisticated digital technologies.

The 10 coastal city living labs involved in the project are: Sligo and Dublin, Ireland; Barcelona/Vilanova i la Geltrú, Benidorm and Basque Country, Spain; Oeiras, Portugal; Massa, Italy; Koper, Slovenia; Gdansk, Poland; Samsun, Turkey.

SCORE will establish an integrated coastal zone management framework for strengthening EBA and smart coastal city policies, creating European leadership in coastal city climate change adaptation in line with The Paris Agreement. It will provide innovative platforms to empower stakeholders' deployment of EBAs to increase climate resilience, business opportunities and financial sustainability of coastal cities.

The SCORE interdisciplinary team consists of 28 world-leading organisations from academia, local authorities, RPOs, and SMEs encompassing a wide range of skills including environmental science and policy, climate modelling, citizen and social science, data management, coastal management and engineering, security and technological aspects of smart sensing research.

EXECUTIVE SUMMARY

This document is a deliverable of the SCORE project, funded under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003534.

The D8.1, related to Task 8.1 and entitled "GIS Based Early Warning and Digital Twin Platform functional requirements", is the first WP8 report, describing the requirements and functionalities that will characterize the GIS based Early Warning and Digital Twin Platform. This document is based on inputs collected by the end users through interviews and sprint workshops under the coordination of WP2. This is the first version based on the answers from the questionnaire, but this document will be updated in D8.2 and D8.3 with results from the workshops.

The aim of this deliverable, is to define the use requirements of the Early Warning and Digital Twin Platform by including the use cases for identification of the needs, requirements, and corresponding functionalities of the system. This is one of the crucial steps for effective project design and represents one of the main objectives of WP8 "Development of integrated early warning support and spatial digital twin solution prototypes".

Indeed, it is critical not to miss the proper knowledge of the requirements and expectations of users (both internal and external to the project) during the project, as this will provide a solid viewpoint on how to handle and assess project objectives.

To this end, a coherent set of requirements have been developed for the Early Warning Support System and Digital Twin suite of design tools based on analysis of gaps between the current state-of-the-art tools, learnings from the SCORE project, and the stakeholder expectations identified in the CCLL (Coastal City Living Lab) questionnaire and workshops. The requirements in this document are the specific functional requirements. Subsequent tasks of the SCORE project will develop these requirements into more detailed technical requirements and software specifications, prior to software coding and integration, then testing and validation.

The overall approach and methodology for user needs and requirements have been defined in this version of the deliverable, and a summary of user stories has been described in detail, while the validation of the user stories will take place after the workshops are organized and will be included in D8.2 and D8.3.

Finally, in the last phase of Task 8.1 related to the deliverables D8.2 and D8.3, the system architecture and design of the components of the GIS Based Early Warning Support and Digital Twin Platform (D8.2) are expected together with the Interface Control Document (D8.3), which will describe all interactions, interfaces, and protocols between the Platform components and between the Platform and external entities. Further exploratory and experimental user workshops and reports will refine the user requirements, while on the other hand, the developers will gain insight into the needed technologies.

LINKS WITH OTHER PROJECT ACTIVITIES

This deliverable represents the first deliverable of WP8, Task 8.1, and describes the functional requirements of the Early Warning Support System and Digital Twin Platform. The platform will be an innovative digital twin to measure climate resilience, thereby promoting the large-scale deployment of EBAs towards the creation of a global market for SCORE solutions. The platform will run multiple models of each coastal city as a Big Cyber-Physical System, integrating data from SIP, including the baseline and climate projection models (WP1, WP3), the EBA database (WP5), risk assessment tools (WP6), socio-economic data (WP7), and sensor data from established sources, as well as the networks of low-cost sensors deployed in WP4. All these connections can be identified in figure 1.

In this regard, the links with other WPs, WP2 and WP4, have been considered during the preparation of this report. WP2 stakeholders were engaged to build an Early Warning Support System and Digital Twin user taskforce. Different questionnaires and design sprint workshops were organised to co-develop the GIS-based collaborative planning framework to be adopted. WP4 provides the sensor technology that will be used by citizens and integrated into the platform. This deliverable will be completed by D8.2, D8.3, the outcomes of T8.1 for the development of Early Warning Support System and Digital Twin Platform components.

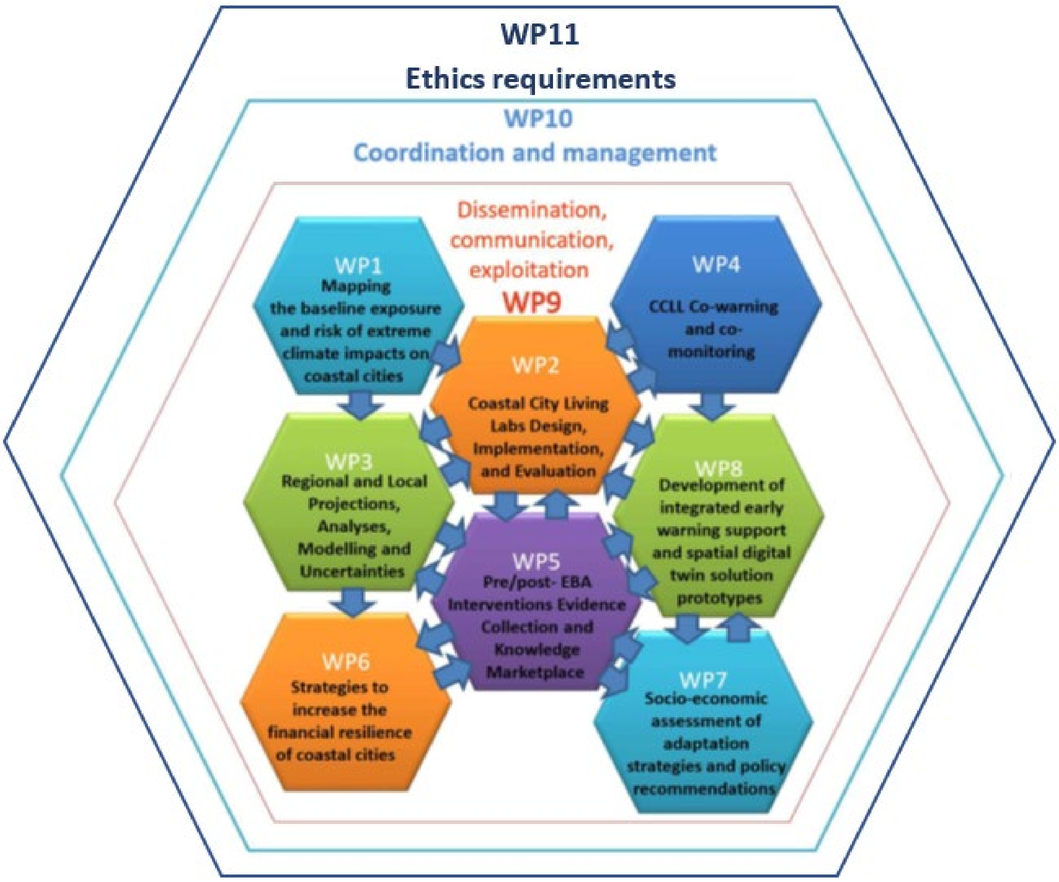

Figure 1 SCORE WPs interaction

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1. INTRODUCTION

1.1. Scope of this report

This report is the result of Task 8.1 "Co-design with stakeholders of the GIS-Based Early Warning Support System and Digital Twin Platform and its functional requirements" from WP8, which was assigned the task with the task of translating stakeholders' needs into a coherent set of detailed functional requirements for the GIS-Based Early Warning Support System and Digital Twin Platform. WP8 is responsible for the creation of prototypes of GIS-based digital twin systems that will offer a virtual environment in which various climate change scenarios and actions may be visualized and optimal solutions discovered. On this basis, comprehensive specifications for the development of Early Warning Support System and Digital Twin will be generated in the present task, T8.1, and subsequent tasks T8.2, T8.3, T8.4, and T8.5, with support from the other WPs via WP5, as seen in Figure 2. Moreover, WP2 stakeholders will be contacted to assist in the formation of an Early Warning Support System and Digital Twin user taskforce. Workshops will be performed to collaboratively build the GIS-based collaborative planning framework that will be used. Local and national stakeholders will participate in seminars to enhance the usability of the early warning module and digital twins. Additionally, Copernicus's existing services (Copernicus.eu) will be evaluated for their effectiveness in integrating with the climate resilience platform. Copernicus is the European Union's flagship Earth observation program, which runs via six broad services: Atmosphere, Marine, Land, Climate Change, Security, and Emergencies. Copernicus is a joint initiative of the European Commission and the European Space Agency. It provides users with trustworthy and up-to-date information on our planet and its surroundings via the delivery of publicly available operational data and services that are open to the public. which will then be converted into design aspects via interviews, surveys, and engagement with stakeholders, and those design functions and processes, including screen layouts, business rules, process diagrams, interfaces, system architecture, and design, will be described in detail.

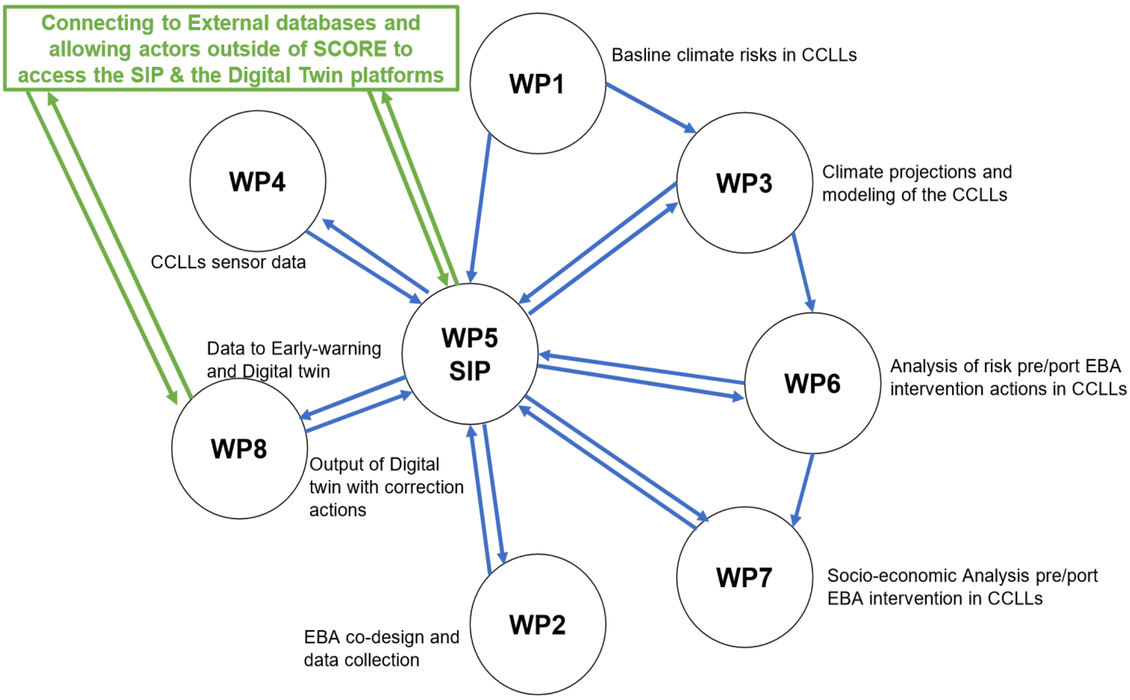

Figure 2: SCORE WPs Connection

The digital platform will be developed using the PowerSchedO processing engine, a business analytics and optimisation solution developed by MBI [1]. Using the object-oriented approach provided by PowerSchedO, a city model will be described using a predefined set of classes (i.e. buildings, roads, beach, docks, etc.). The platform will run multiple models of each coastal city as a Big Cyber-Physical System, integrating data from SIP, including the baseline and climate projection models (WP1, WP3), the EBA database (WP5), risk assessment tools (WP6), socio-economic data (WP7) and sensor data from established sources as well as the networks of low cost sensors deployed in WP4, see Figure 3.

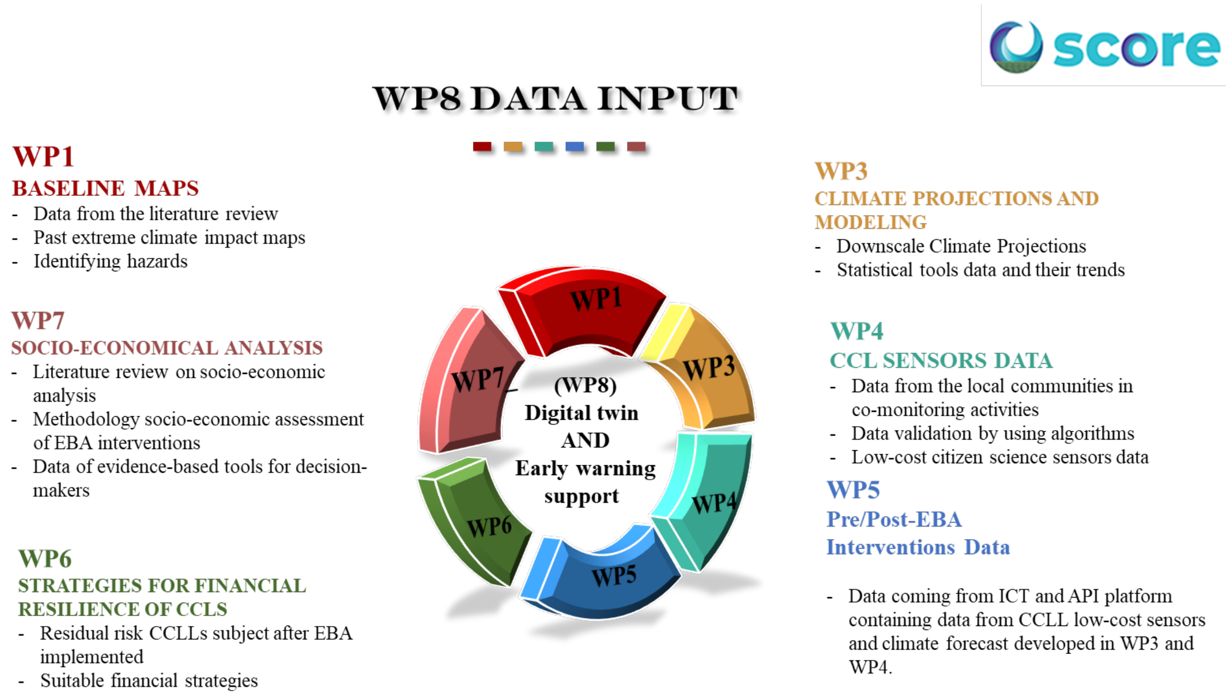

Figure 3: WP8 data input

AI and Big Data algorithms will be utilised for data mining of this complex system, providing real-time analytics and corrective intervention actions to improve the coastal city climate resilience taking into account socio-economic and financial factors.

The "Early Warning Processing" module will perform specific short-term forecasts on weather conditions, evaluating how these will impact the city and its inhabitants (e.g. forecasting of street closures due to heavy rain and impact on traffic flow). The digital prototypes will assist local and national governance in the definition and implementation of resilience management strategies, by taking also into account demographics, water supply, climate and land use changes, adaptation measures and coastal ecosystem services.

The components that will be developed during Task 8.2 and Task 8.3 will be integrated with the GIS Based Early Warning and Digital Twin Platform, which will provide a visual climate resilience metering tool for all CCLLs. This platform will analyse collected data and recommend corrective actions to support climate resilience, optimised for sustainability, cost and socio-economic impact, thereby significantly reducing the timeline for implementation of successful mitigation actions. Different kinds of users can use the available tools, models and mechanisms for effective monitoring and control of the climate resilience.

In this perspective, the SCORE ecosystem can be defined as the community of internal and external stakeholders of the project in conjunction with its core technology framework. Understanding the needs and expectations of the SCORE's stakeholders is of utmost importance as it may offer a fresh and valuable perspective on how to tackle the goals and objectives of the project. This deliverable pursues this direction and focuses on the involvement of stakeholders and extrapolation of their needs as well as their implementation priorities.

To this end, the current version of this deliverable will be updated in D8.2 and D8.3 after co-designing with stakeholders in SCORE workshops.

1.2. What is SCORE's Early Warning Support System and Digital Twin's Approach?

As previously stated, extreme weather events becoming more intense, coastal erosion becoming more severe, and sea-level rise becoming more significant, are all key concerns that European coastal communities must address as soon as possible. Through a network of ten coastal city 'living labs' (CCLLs), SCORE proposes a co-creation method for promptly, equitably, and sustainably increasing coastal city climate resilience through EBAs and advanced digital technologies by utilizing open, accessible spatial 'digital twin' tools and engaging citizen science in the development of prototype coastal city early warning systems, SCORE aims to enable smart, real-time monitoring and control of climate resilience in European coastal cities. As part of its mission to promote climate resilience, business opportunities, and financial sustainability of coastal cities, SCORE will create new platforms to empower stakeholders in the implementation of EBAs.

Figure 4 presents SCORE's early warning system and digital twin approach, both of them will be deployed step-by-step during the course of the project. To begin, as depicted in this figure, the first and most important step will be the development of an overall baseline map of all CCLS regions. These data will be derived from WP1, which will contain all of the information from previous literature as well as information on past extreme climate impacts. Furthermore, WP1 will provide information on historical hazards. Similarly, WP3 will be responsible for producing projections for all of the CCLLs region data, including all of the downscaled forecasts of future data and associated trends, evaluating how these will impact on the city and the inhabitants. Whereas the WP4 will derive information from currently available and already operational environmental sensors (such as anemometers, rain gauges, weather radars, and water level sensors), it will also derive information from novel citizen science sensors, which will be used to complement real-time data in the Digital twin technology. The observation data, on the other hand, will be generated from WP5, WP6, and WP7, which will comprise all EBA and socio-economic data for all of the CCLL regions.

A number of major coastal hazards that occur over the CCLLs include Coastal flooding, Land flooding, Coastal Erosion, and Coastal Storm Surge; and data from the relevant WPs will be pooled to develop an early warning support system for these CCLL hazards. Following the collection of data, the SCORE experts will classify all hazards as either red, yellow, or orange alerts, as seen in Figure 4 (see below). The next step will be to create a GIS-based digital twin platform for early warning of these dangers. This digital twin platform, which will be accessible online, will allow all stakeholders of CCLLs to appropriately and rapidly respond to the extreme climate event.

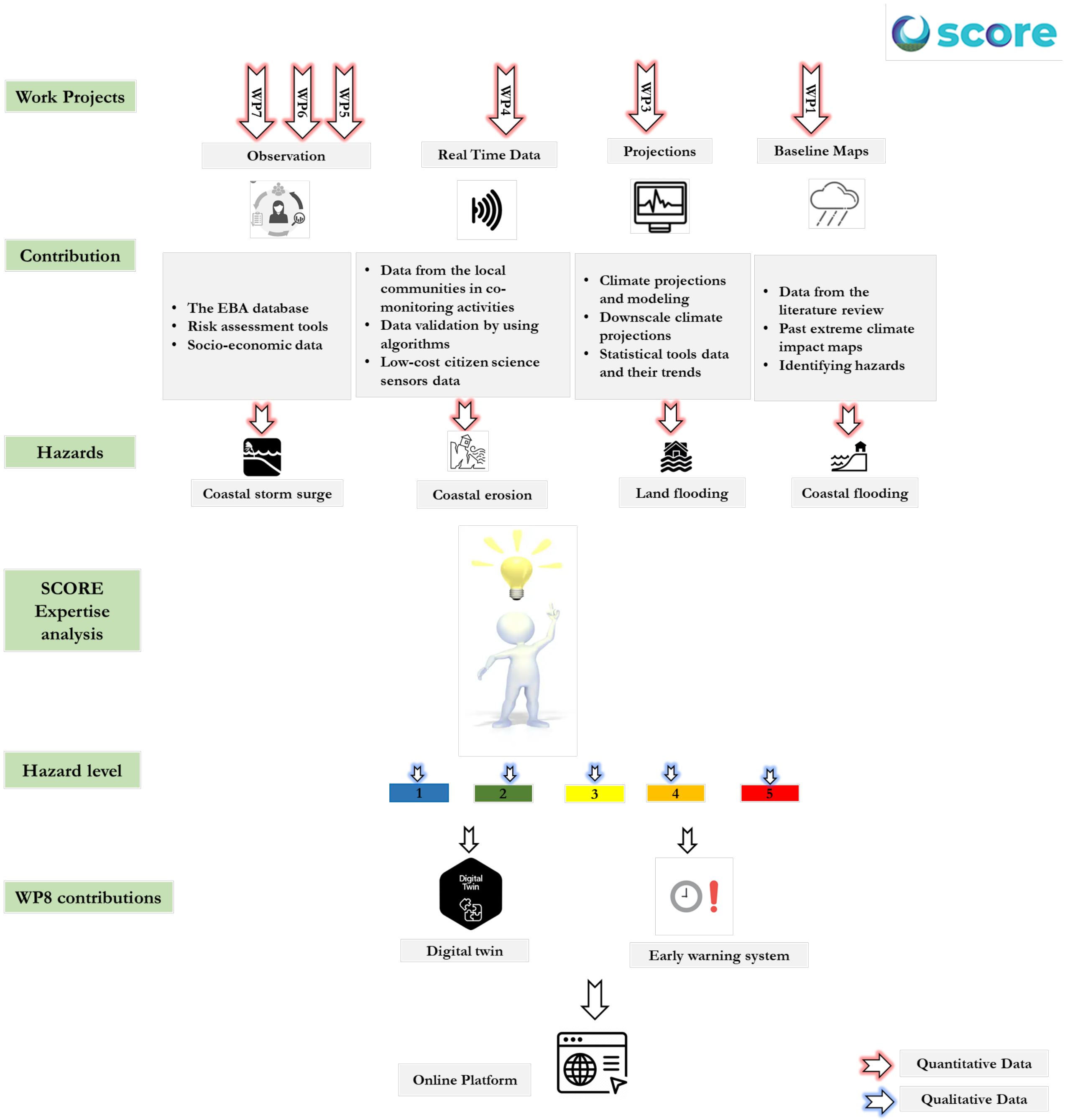

Figure 4: SCORE's Early Warning System And Digital Twin's Approach

1.3. Current stage of EWSS and DT

This section reviews existing EWSS techniques and Digital twin approaches at the global level, as well as the challenges that will be faced in the endeavour to adapt to climate change and reduce hazard risk.

1.3.1. Early Warning Support Approach

As a part of disaster risk reduction and climate change adaptation, early warning systems (EWSS) play an important role in preventing or mitigating the effects of hazards. For an early warning system to be effective, it must actively engage the people and communities at risk from a variety of hazards, facilitate public education and awareness of risks, disseminate messages and warnings efficiently, and ensure that there is a constant state of preparedness and early action is enabled. Early warning systems are only valuable if their advantages are appreciated by those who live in the affected area.

Over the last 15 years, there has been a growing interest in the potential of EWSS in global to local climate change adaptation and hazard risk reduction efforts. Throughout this period, EWSS has gained increasing attention within the scope of international agreements, conferences, and action plans. However, more than two-thirds of coastal European cities are dealing with extreme weather events, coastal erosion, and sea-level rise. These challenges will grow as climate change causes more intense weather. Early Warning Support System (EWSS) can help mitigate flood risk by detecting circumstances and supporting actions to be taken in advance to mitigate the consequences of a disaster before it happens, as well as giving real-time information during an incident. As a result, EWSSs serve many functions as general information systems, decision support systems, and alarm systems for a variety of stakeholders, including the government, commercial organizations, and the general public. Therefore, the main aim of the SCORE is to involve citizen science in providing prototype coastal city early-warning systems and will enable smart, instant monitoring and control of climate resilience in European coastal cities.

1.3.2. EWSS Framework for European Cities

European countries have a long history of developing early warning systems, particularly for flood and flash flood, storms, forest fires and heatwaves. Climate-related hazards influence a wide range of areas, including health, disaster risk reduction, agriculture, forestry, buildings, coastal and urban regions, and coastal and urban areas. Early warning systems may aid other sectors, such as transportation and tourism, if roads or railroads are blocked in advance before people are harmed, or if tourists are told to stay inside during extreme weather periods.

Flooding is one of the most significant natural disasters that Europe has to deal with nowadays. Since 1980, the frequency of extremely severe floods in Europe has grown, although there has been a significant increase in interannual variability, which may be attributed to a variety of factors including land-use changes, and more heavy precipitation in certain regions of Europe. It is predicted that climate change would intensify the hydrological cycle and increase the frequency and severity of flood events throughout most of Europe. Throughout Europe, it is expected that pluvial floods and flash floods, which are driven by extreme local precipitation events, will become more common in the future. In Europe, coastal storm surges and flooding are the most common and expensive severe weather occurrences, accounting for 69% of all-natural catastrophic damages. France, for example, was only moderately affected by the winter storm Xynthia in 2010, which resulted in 51 deaths and losses of more than EUR 1.5 billion. Moreover, more than two-thirds of European cities must deal with flood risk management issues on a regular basis; these are issues that will worsen as climate change effects result in more extreme conditions. Early Warning Systems can play a crucial role in mitigating flood risk by detecting conditions and predicting the onset of a catastrophe before the event occurs, and by providing real-time information during an event. EWSSs thus fulfil multiple roles as general information systems, decision support systems, and alarm systems for multiple stakeholders including government, private companies, and the general public.

Figure 5: The steps that led to the establishment of the flood early warning system [2]

In order for a flood early warning system to be effective, several phases are involved, as presented in Figure 5. The first and most important step is to recognize the threat, together with frequency, and likelihood of the occurrence of the hazard. Furthermore, it is important to understand the historical pattern and trends in the components, as well as the availability of historical data, over time, as described in Figure 5. The second phase involves monitoring, predicting, and warning of risks trends and their tendency in the future. The third step involves the community members who are at risk and ensuring that all warnings are sent to everyone who is involved in that specific region. And, finally, the last phase is to respond to and prepare against the risk.

Some EWSS approaches used for the climate-related risk are:

- Meteoalarm:

  Meteoalarm is a joint effort from EUMETNET (The Network of European Meteorological Services) that provides alerts in Europe for extreme weather events, including heavy rain with risk of flooding, severe thunderstorms, gale-force winds, heatwaves, forest fires, fog, snow or extreme cold with blizzards, avalanches, or severe coastal tides [3].

- Copernicus Emergency Management Service (CEMS)

  ECMWF helps to the Copernicus Emergency Management Service (CEMS), namely the flood and fire early warning systems. The CEMS provides emergency response information for a variety of disaster types, including meteorological hazards, geophysical hazards, deliberate and unintentional man-made disasters, and other humanitarian disasters, as well as activities related to prevention, preparedness, response, and recovery [4].

- Risk Data Hub of the Disaster Risk Management Knowledge Centre (DRMKC)

  The Risk Data Hub of the Disaster Risk Management Knowledge Centre (DRMKC) managed by DG JRC provides curated EU-wide risk data via hosting datasets and through linking to national platforms [5].

- Building railway transport resilience to Alpine hazards in Austria

  Meteorological extreme events pose a great risk for railway infrastructure and the safety of passengers. In the future, climate change will presumably have serious implications on meteorological hazards in the Alpine region. To minimize direct damage to railway infrastructure, structural protections measures are implemented by the ÖBB Infra AG along with its partners where this is economically, technically and environmentally feasible. However, especially in the alpine environment full protection is not possible and the risk profile continuously changes due to climate change. To ensure the safe and continuous operation of the network and the safety of passengers, a complementary weather monitoring and early warning systems was installed [6].

- National Heat-Health Action Plan (HHAP) of North Macedonia

  The National Heat-Health Action Plan (HHAP) of North Macedonia was developed in 2011 and approved in 2012, following the National Climate Change Health Adaptation Strategy and Action Plan. The HHAP aims to decrease morbidity and mortality connected with extreme temperatures and heatwaves. It foresaw the implementation of a heat health warning system, currently in place and operational, as well as a series of actions aiming at mainstreaming health protection in other relevant policies, raising the citizens and health sector workers' awareness about consequences of climate change and mobilizing the resources for managing the heat effects on health [7].

- Tatabánya, Hungary, addressing the impacts of urban heatwaves and forest fires with alert measures

  The City of Tatabánya has a Local Climate Change Strategy and Action Plan, approved in 2008, which has been implemented to address diverse climate hazards, which impact people's health (e.g., heatwaves and heat stress, UV radiation, forest fires). It provides alert about urban heatwaves and forest fires [8].

- Weather Alert Emilia-Romagna

  In Emilia Romagna region (Italy), a regional Weather Alert Web Portal has been developed in parallel to the development and refinement of real-time hydro-meteorological monitoring technologies and a widespread risk communication program [9].

1.3.3. Digital twin approach

The "digital twin" (DT) idea enables the creation and maintenance of virtual representations of real-world objects and processes. In other words, the DT technique is based on the capability to automatically receive and interpret data flows produced by distributed "internet of things" (IoT) sensor devices. The city's DT is progressively being filled with data from the real city, which is acquired in real-time via installed IoT equipment and urban information systems. DT assists in projecting changes in the status of urban infrastructure and in providing optimal solutions by evaluating data on the dynamics of people and transportation, their interdependence, and their variations in time and location. Furthermore, regardless of the current state, the digital twin allows analysts to answer "what if" questions, assisting in understanding how cities equipped with intelligent technology will function in specific economic, environmental, and social conditions, as well as identifying the factors that contribute to potential failures.

Initially, Digital Twin technology was only introduced for building sustainability and efficiency, but in the last ten years, scientists' interest has shifted to digital twins as a solution for climate change, and with the help of the DT, we can more easily support the Emergency Management (including awareness and preparedness) as well as to mitigate the risk and impacts of natural hazards such as flood, coastal erosion, extreme temperature, and sea-level rise. Furthermore, European coastal communities are already dealing with all of these hazards and incurring losses on a regular basis. As a result, the EU H2020 has announced many new projects towards the digital twin of European nations. SCORE EU 2020 project will establish the online GIS-based digital twin solution prototypes, which will provide a virtual environment in which different climate change scenarios and actions can be visualised and optimum solutions identified.

1.3.4. Other Digital twin projects and approaches used for the climate-related risk

The following are ongoing projects related to digital twin technology used for the extreme climate early warning system:

Destination Earth (DestinE)

Objective :

Destination Earth aims to develop a high precision digital model of the Earth to model, monitor and simulate natural phenomena and related human activities.

Explanation:

As part of European Commission’s Green Deal and the Digital Strategy, Destination Earth (DestinE) will contribute to achieving the objectives of the twin transition, green and digital.

DestinE will unlock the potential of digital modelling of the Earth system. It will focus on the effects of the climate change, water and marine environments, polar areas, cryosphere, biodiversity or extreme weather events, together with possible adaptation and mitigation strategies. It will help to predict major environmental degradation and disasters with unprecedented fidelity and reliability.

By opening up access to public datasets across Europe, DestinE represents also a key component of the European strategy for data.

Expected Outcome:

- Continuously monitor the health of the planet: For example, to study the effects of climate change, the state of the oceans, the cryosphere, biodiversity, land use, and natural resources.
- Support EU policy-making and implementation: For example, to assess the impact and efficiency of environmental policy and relevant legislative measures.
- Perform high precision, dynamic simulations of the Earth’s natural systems, focusing on thematic domains such as marine, land, coasts, and atmosphere.
- Improve modelling and predictive capacities: For example, to help anticipate and plan measures in case of storms, floods and other extreme weather events and natural disasters.
- Reinforce Europe’s industrial and technological capabilities in simulation, modelling, predictive data analytics, artificial intelligence (AI) and high performance computing (HPC).

Preparing for DestinE:

The first stakeholder workshop on DestinE was organized in November 2019 to announce the initiative and collect feedback from potentially interested stakeholders. It brought together a large number of potentially interested parties from public authorities and the industrial and scientific communities.

To explore the potential application areas and parallel initiatives, the Joint Research Centre conducted a Study on DestinE use cases analysis and a Survey on digital twin initiatives in EU countries, with contributions from the ESA, ECMWF and EUMETSAT, Commission services and agencies.

A further *series of open stakeholder workshops* took place:

- In October 2020, two workshops on user specifications for the first two Digital Twins (extreme natural events and climate change adaptation.
- In November 2020, a workshop on DestinE system architecture design.
- In February 2021, a Policy user engagement workshop was organised for discussing the two priority twins with potential policy users and their use case proposals.

Timeline:

DestinE will be developed gradually through the following key milestones:

By 2024: Development of the open core digital platform and the first two digital twins on extreme natural events and climate change adaptation.

By 2027: Integration of additional digital twins, like the digital twin of the ocean, to serve sector specific use cases into the platform.

By 2030: A ‘full’ digital replica of the Earth through the convergence of the digital twins already offered through the platform. Source – [10]

Preparedness and Resilience Enforcement for Critical INfrastructure Cascading Cyberphysical Threats (PRECINCT)

Objective:

The interrelationships between critical infrastructures (CIs) have become more complex, rendering the security and resilience management of cyber-physical attacks and natural hazard threats more challenging.

Explanation:

The EU-funded PRECINCT project will connect private and public CI stakeholders in a geographical area to a cyber-physical security management method that will produce a protected territory for citizens and CIs. The project will deliver a framework specification for systematic CI security and resilience management, a cross-facility collaborative management infrastructure enabling stakeholder communities to create AI-based PRECINCT ecosystems and increased resilience support services, a vulnerability assessment tool using serious games, PRECINCT’s Digital Twins, and PRECINCT Ecosystems in four large-scale living labs and transferability validation demonstrators.

EU Critical Infrastructures (CIs) are increasingly at risk from cyber-physical attacks and natural hazards. Research and emerging solutions focus on the protection of individual CIs, however, the interrelationships between Cis has become more complex for example in smart cities and managing the impacts of cascading effects and enabling rapid recovery is becoming more pertinent and highly challenging.

Expected outcome:

PRECINCT aims to connect private and public CI stakeholders in a geographical area to a common cyber-physical security management approach which will yield a protected territory for citizens and infrastructures, a 'PRECINCT' that can be replicated efficiently for a safer Europe and will deliver:

- A PRECINCT Framework Specification for systematic CIs security and resilience management fulfilling industry requirements.
- 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.
- PRECINCT's Digital Twins to represent the CIs network topology and metadata profiles, applying closed-loop Machine Learning techniques to detect violations and provide optimised response and mitigation measures and automated forensics.
- Smart PRECINCT Ecosystems, deployed in four large-scale Living Labs and Transferability Validation Demonstrators, will provide measurement-based evidence of the targeted advantages and will realize Digital Twins corresponding to the CIs located therein, include active participation of emergency services and city administrations with results feeding back to the Digital Twins developments.

- Sustainability related outputs including Capacity Building, Dissemination, Exploitation, Resilience Strategy, Policy/Standardisation recommendations. Source: [11]

1.3.5. Challenges

The difficulties below are general in nature but may be seen as addressing natural environmental hazards associated with EWSS that need monitoring and defensive structures.

- How to translate data from the CCLLs and external databases e.g., baseline and forecasting climate hazard models (WP1, WP3); sensor data (WP4); financial risk assessment data (WP6), and socioeconomic data (WP7), all of which is stored and extracted from SIP (WP5) into platform-usable pieces of information?
- How to run projection algorithms to detect critical coastal conditions and provide early warnings support system?
- How to conduct an evaluation of mitigation activities and provide city-specific suggestions for long-term, cost-effective enhancement?
- How can thousands of sensor feeds be monitored?
- How to host and manage various early warning systems for all CCLLs?
- How to Collaboratively Design an Open-Access Platform for GIS-Based Early Warning and Digital Twin Platforms for All CCLLS?

1.4. Current Experience of the CCLLs with EWSS and DT

The ten Coastal City Living Labs that are part of the SCORE project have different capacities and skills in reference to Digital Twin and EWSS.

CCLLs that have some previous experience with Digital Twin technologies:

- Piran (Koper), Slovakia;
- Dublin, Ireland;
- Sligo, Ireland;
- Massa, Italy;
- Province of Barcelona, Spain.

The remaining CCLLs - namely, Alicante, Samsun, Basque, Gdsank and Lisbon - don't have any relevant experience with Digital Twin technology or Early Warning Systems and need support and technical training in these. Even those cities that do have experience with Digital Twin, for instance Dublin, still want further training and assistance throughout the SCORE project, to effectively make use of digital twin technologies. Sligo and Gdsank are the only cities that do not require any need enhancement in the technical capacities. Out of all the ten cities, Sligo, Dublin, Piran (Koper), Massa and Vilanova (Barcelona) are experienced in the numerical scoring of Digital Twin Solutions based on the answers of the questionnaires that was circulated to all 10 CCLLs during January 2022, while the remaining cities are not. Only Piran (Koper), Massa and Vilanova (Barcelona) provided qualitative information on their experience with Digital Twin technologies.

1.5. Objectives and Expected Outcome

Objectives

The objective of WP8, as stated in the Description of Works "*is to develop a GIS Based Early Warning Support and Digital Twin Platform and deploy it in the SCORE CCLLs. The Platform will assist local and national governance in collaborative resilience management strategies, considering demographics, water supply, climate and land use changes, adaptation measures and coastal ecosystem services*."

In more detail this means:

- to design, implement, and evaluate a novel Coastal City Living Lab framework for 10 coastal cities, integrating Ecosystem-Based Approaches with smart technologies (e.g. sensors, digital twin solutions) to enhance climate change adaptation and resilience;
- to develop digital twin solution for smart instant monitoring and control of climate resilience;
- to develop, pilot and demonstrate a smart city early warning support system for extreme events.

Outcomes

The main outcomes of WP8 are as follows:

- multiple models of each Coastal City as relevant Big Cyber-Physical System receiving and processing heterogeneous data streams from a large number of low-cost sensors in coastal urban areas;

- the digital twins will provide a visual climate resilience metering tool for all CCLLs;
- the digital twins will analyse collected data and recommend corrective actions to support;
- Cclimate resilience, optimised for sustainability, cost and socio-economic impact, thereby significantly reducing the timeline for implementation of successful mitigation actions;
- prototype of an early warning system for extreme events in the CCLL pilots;
- new instant monitoring solution for real-time data analysis of large heterogeneous sensor and IoT networks;
- the data from existing sensor networks that are currently used by the municipalities are complemented with data from low-cost sensors (citizen science kits) and can fill the spatial/temporal gaps to produce more solid coastal city early-warning systems

1.6. Related Programmes, Policies, and Projects

1.6.1. Related policies and programs

This section provides an overview of the programs, policies, and initiatives that have connections to or are pertinent to GIS-based digital twin technology and early warning system for climate resilience. Please note that the listing is not exhaustive and does not pretend to be complete.

INSPIRE Directive (2007/2/EC)

In May 2007, the INSPIRE Directive came into force, creating a geographic information infrastructure in Europe to assist Community environmental policies and other policies or actions that may have an effect on the environment. The INSPIRE Directive's principal goal is to promote the exchange of geographical information for environmental policies and operations across public sector institutions and borders. INSPIRE also encourages the reuse of public sector geographic data by third parties to improve public access to spatial data throughout Europe. Its adoption promotes public and private sector efficiency and effectiveness. Companies seeking geographical and environmental data may save 15% in time and money.

The European Parliament and Council adopted Directive 2007/2/EC on 14 March 2007 creating an Infrastructure for Spatial Information in the European Community (INSPIRE). It came into action on May 15, 2007.

The Regulation mandates that standard Implementing Rules (IR) be implemented in a number of key areas to guarantee that the Member States' spatial data infrastructures are compatible and useable over the specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting). These IRs become Commission Decisions or Regulations and are fully binding. A regulatory body comprising of representatives of the Member States and led by a Commission representative assists the Commission in establishing such regulations (this is known as the Comitology procedure) [12].

Flood Directive 2007/60/EC

On 26 November 2007, Directive 2007/60/EC on the evaluation and management of flood risks came into effect. The European Commission originally proposed the Directive on 18 January 2006, and it was published in the Official Journal on 6 November 2007. Its objective is to mitigate and manage flood-related threats to human health, the environment, cultural heritage, and economic activities. By the end of 2009, the Directive has been implemented into national law in all EU Member States. The Directive requires Member States to conduct an initial assessment by 2011 to identify flood-prone river basins and related coastal regions. They would subsequently be required to develop flood risk maps for such zones by 2013 and to implement flood risk management strategies centered on prevention, protection, and readiness by 2015. The Directive covers both upland and coastal waterways across the EU. Additionally, the Directive underlines the public's rights to access this information and to participate in the planning process [13].

The Marine Strategy Framework Directive

The ambitious Marine Strategy Framework Directive of the European Union aims to safeguard the marine environment more efficiently across Europe. On 17 June 2008, the Marine Strategy Framework Directive was approved. Additionally, the Commission developed a comprehensive set of criteria and methodological standards to assist Member States in implementing the Marine Strategy Framework Directive. These were amended in 2017, resulting in a new Commission Decision on Environmental Good Standing.

In June 2020, the Commission approve a report on the Marine Strategy Framework Directive's first implementation cycle. This report, required by Article 20 of the Directive, demonstrates that, while the EU's framework for marine environmental protection is one of the most comprehensive and ambitious in the world, it requires strengthening to address major pressures such as overfishing and unsustainable fishing practices, plastic litter, excess nutrients, underwater noise, and other forms of pollution [14].

JRC – ISPRA

Apart from developing an early warning system (EFAS (the European Flood Alert System), JRC conducts case studies on flood prevention and forecasting in the Elbe and Danube, flash floods and the consequences of climate change, and flood risk mapping [15].

Integrated Coastal Zone Management and Maritime Spatial Planning

Draft European Union Directive on the establishment of a framework for marine spatial planning and integrated coastal management. On March 12, 2013, the European Commission announced the commencement of a new collaborative project on integrated coastal management and marine spatial planning. It is intended to establish a framework for maritime spatial planning and integrated coastal management in EU Member States with the goal of promoting the sustainable growth of maritime and coastal activities as well as the sustainable use of coastal and marine resources. The proposal is being presented in the form of a draft Directive [16].

1.6.2. SCORE data management plan (DMP)

SCORE's DMP is part of the WP5 delivery and is collaboratively created by the coordinator, CNR, and the WP5 leader, UNIPI, in accordance with Horizon 2020's standards on FAIR data management. Numerous (such as CERIF or Data Package) and trusted repository (such as Zenodo, Dryad, or CINES) are considered for data curation and preservation., the primary goal of that document is to address specific questions such as how research data will be handled during and after the project, the list of data collected, processed, and generated, the methodology and standards to be used, which data will be made openly available.

Figure 6 depicts the SCOREs DMP template used in WP5, which was designed in WP5-Task 5.2 and explains the many types of data that will be gathered during the project and stored in the SCORE ICT platform (SIP), which will include a database and all necessary interfaces. Despite their heterogeneity, the data collected from all CCLLs of all work projects can be roughly divided into two categories: a) raw data collected by meteorological stations service data and low-cost sensors envisaged in citizen science approaches (WP4); b) processed data from other WPs. The prior collection of data (i.e. raw data) is not FAIR and will not be made available in its entirety; rather, it will serve as the foundation for further processing and research operations. After a rigorous review by the Innovation Board for potential protection and exploitation, the latter data set (i.e. processed data) will be made accessible either directly via the SIP or through repositories, in accordance with an Open Science strategy. The first intention is to both put data into existing repositories and to open a portion of the SIP directly, namely the piece holding publishable, processed, and hence FAIR, data. WP9 will assess the solutions' replicability in other coastal (and non-coastal) cities as a project goal, focusing on dissemination/communication initiatives such as spreading the SIP open section to reach the greatest number of prospective data consumers. Additionally, the SIP will be connected to other databases produced as part of international initiatives that include data related to the SCORE goals, in order to maximize mutual advantages. To that end, the first edition of the D5.2 Data Management Plan Document is now available. Additionally, the document will be updated with time [17].

Figure 6: SCORE's Data Management Plan

2. User requirement development

SCORE outlines a co-creation strategy, developed via a network of 10 Coastal City 'Living Labs' (CCLLs), to rapidly, equitably and sustainably enhance coastal city climate resilience through EBAs and sophisticated digital technologies setting. CCLL is an innovation intermediary, which orchestrates an ecosystem of actors in a specific region to tackle specific challenges related to sea level rise, coastal erosion and extreme events. By co-creation involving iterations, end-users and relevant stakeholders (e.g. public actors, private actors, knowledge institutions, civic groups and/or non-government organizations, including local communities) in each CCLL are involved in the development process and regularly evaluate and provide feedback for improvement. With this in mind, when we collect user requirements we interact with the end-users (user centred) to capture what they really want. It is in this respect also important to define who the users will be.

The co-creation process included several steps: first, several questionnaires (the first one at the proposal stage of the project, the second one in October 2021 and finally another one in January 2022) were conducted to be followed by workshops (March-May 2022) where user stories will be fully defined.

2.1. Target Group – Stakeholders

This section describes the stakeholder analysis. It lists the demands and requirements of the different stakeholders for EWSS and DT. Digital Twin is defined as follows: a computer program (a virtual representation) that uses real-world data to create simulations that can predict how a product or process will perform if parameters are changed

The first step of the stakeholder analysis was to write down the known issues in an outline. For this, we address three questionnaires to CCLLs, one in the proposal stage of the project, a short one in October 2021, and the last one in January 2022, for verifying the outline of the EWSS and DT. With these details from the CCLL responses, the current report was completed.

The main stakeholder groups (audiences) are identified based on the response to the first and last questionnaire and are presented in Table 1. This table is based on the Quadruple Helix Model (Figure 7) developed as part of the CCLL framework. The Quadruple Helix Model of innovation recognizes four major actors in the innovation system: science, policy, industry, and society. In keeping with this model, more and more governments are prioritizing greater public involvement in innovation processes as shown in Figure 7.

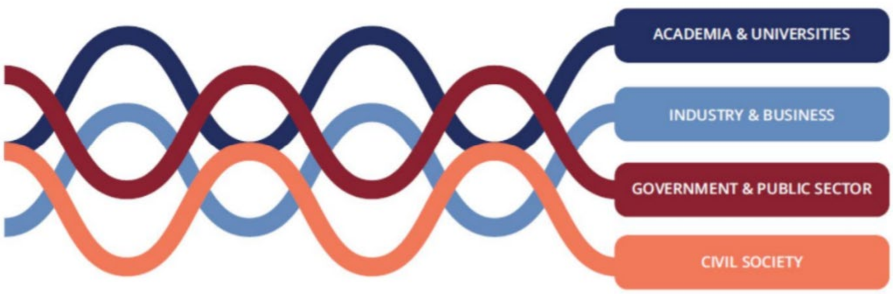

Figure 7 Quadruple Helix Model [18]

Stakeholders are all parties that either affect or can be affected by a certain problem/solution. All the identified stakeholders will participate in SCORE workshops which will run in March-May 2022.

Table 1: Stakeholder groups

Stakeholder groups	Description
Academic and Research • climate model experts, climate scientists, and other environmental scientists, engineers, social scientists (outreach experts) • **EU projects and networks working in similar domains**	This group targets all research communities interested in the project's developments, results, and innovation which can be beneficial for their activities. This specifically targets the fields in resilience and climate change. The research community also includes relevant project partners and offers the opportunity to establish quick links among parties through joint actions.
Government and Public Sector • Policymakers /Governance: Chambers of Commerce, City Councils, local/regional politicians • Housing, planning authorities and other public bodies • Other coastal city management authorities	This group will be identified very early in the life of the project and will target all the important political and technical actors in European coastal cities (not only from countries of the consortium). This is a wide group encompassing innovation-driven local, regional, national authorities, representatives & associations, Ministries, parliaments, and national & international Public Administrations.
Industries and Business • Producers of methodologies and technologies to reduce the impacts of climate change on the territory • weather station/ sensor manufacturers, software developers • Civil Engineers, planners • Insurance companies / financial advisors • **European and international networks and European technology clusters**	This is a wide group encompassing innovation-driven local, regional, national authorities, representatives & associations. This group also includes relevant European technology clusters (3D grupa , AclimaBasque Environment Cluster - Asociación Cluster de Industrias de Medio Ambiente de Euskadi, AVAESEN, Capenergies)
Civil Society : General public, Citizen Interest Groups, NGOs, Community Action Groups	This consists of a general audience and other actors not identified as directly targeted groups by the project, though this group can have a strong interest in the project.

An end-user is the person who will actually uses the product and/or services at the end of an innovation project. In other words, the person which the product/service was designed for. For the EWSS and DT several groups of potential **end-users** are identified as follows:

- Municipalities, e.g. city planners;
- Emergency response authorities - responsible for emergency management during extreme events;
- Public water management authorities - for the day-to-day management and regular audits of flood protection infrastructure; also for emergency repairs and emergency flood management and other coastal issues and measures;
- The general public in areas that are at risk of identified issues according to the questionnaire; benefit from higher safety but they are not a direct partner in the project. Indirectly they are very important because the safety of the general public is the ultimate objective and the –perceived –improvement of safety will steer political and financial decisions regarding the implementation of SCORE-based EWS’s and DT’s.

2.2. Questionnaires and workshops

During the proposal stage, an online questionnaire survey with 113 questions was conducted by the project consortium to understand the specific needs and expectations of the CCLLs. The questionnaire survey included, among others, basic information (geographical coastal area, population, environmental contextual conditions, natural and climatic related hazards, impacts), objectives for creating and implementing the CCLL, expected outcomes, potential stakeholders, technical and financial capacities, previous experience in relevant projects and level of expertise and experience in different activities associated with each WP. A rubric was developed to score the CCLLs based on their responses which allowed for cross-comparison.

This questionnaire was updated with two new questionnaires which were run in October 2021 (a short questionnaire with only 8 questions) and January 2022 (a longer questionnaire containing more than 180 questions). For the questionnaire and answers see Sharepoint internal platform [19].

Respondents had to answer different questions about stakeholders, if they were willing to take part in the SCORE early warning support experimentation, and if they had prior experience with digital twin concepts.

These results will explored in further depth during the CCLL workshops, and therefore, this document will be updated in D8.2 and D8.3 after organising these workshops. In total, there will be 10 workshops (1 for each CCLL) of 3 days each; some of those workshops might be virtual online workshops due to the local COVID-19 restrictions. Within these workshops, a special slot will be dedicated to WP8 in order to get all the information needed from stakeholders. In order to help identify user needs and visions a guiding list of questions will be used in workshops. The responses to these questions can be collected through a variety of methods depending on the local context (e.g. interviews or focus groups) and the preferences of the end-user representatives. It is important to mention that the guiding questions are not focused on climate resilience, but rather begin with visions to first understand needs as the basis for the subsequent development of the EWSS and DT.

2.3. User stories collection and analysis

The user stories represent the key requirement on the SCORE EWSS and DT. These will be collected during workshops using tools such as Persona, Participatory Mapping, Spatial SWOT, Problem Tree Analysis, Brainstorming with Cards, Mental Mapping, Guided Tour, Collage, Problem Definition Canvas, and more. The most useful tool might be Persona, which allows to understand users' needs and problems in a specific context (not their entire life) to focus the design process toward specific users. The author of a User Story states their role and expresses her/his preferences by stating what they want to accomplish and why in SCORE.The basic template of a user story is:

"I, as <A ROLE> want to <GOAL>, so that <REASON>".

As an example, the stakeholders will write simple one-sentence user stories of what they want the EWSS and DT to do:

"I want, as a citizen, to be warned when my street will be flooded, in order to take action in time".

The user story can be interpreted as the wish of a specific user for a specific feature or functionality. Each user story will be then discussed among the relevant stakeholders to ensure a mutual understanding of the needed functionality from a user's perspective and to clarify how it should and can be implemented technically. This will result in a collection of better-defined user stories, which served as a first set of end-user requirements. These stories will be grouped into story maps, which create a visual overview by clustering similar features, bringing features in a logical sequence and matching sub features to their parent features where possible. The story maps will be further discussed with software experts aiming to further define a set of functional requirements that would feed analytics development and dashboard design.

2.4. Summary of the use cases and user requirements

From the methods of use case collection detailed above, 15 potential SCORE use cases have been collected so far across all of the CCLL (Table 2). Use cases are presented in narrative form for optimum clarity, and also to help with framing development efforts towards their implementation by SCORE partners.

Table 2: User stories and user requirements based on questionnaire's answers

No	Role (As a ...)	Goal (I want ...)	Reason (So that ...)
1	Citizen	... easily accessible information on upcoming extreme weather events.	... I can buy insurance to protect myself, my family and my home accordingly.
2	Fisherman	... effective measures on coastal storms/flooding/erosion through digital twin and early-warning systems.	... I can protect myself better against extreme weather events when fishing.
3	Planner	... clear scientific data on coastal floods based on digital twin technologies	... I can create effective coastal management plans accordingly
4	NGO	... to be able to visualise and download data on the effects of extreme weather	... I can create schemes to benefit these disadvantaged groups accordingly

		events on socially vulnerable populations	
5	Academic/ Researcher	… accurate models to understand the impact of CC on the coastal cities based on digital twin technologies	… I can create simulations to better understand the effect of climate projections at urban scale and conduct analysis as part of my research
6	SCORE Project Officer	… to understand the various uses of early-warning systems and digital twin technologies	… I can effectively communicate these to the relevant stakeholders, policymakers and citizens
7	Businessman	… I want information on extreme weather events through digital twin technologies	…. I can better understand how these will affect my business activities and also insure my business against risk
8	Policymaker	… accurate data on extreme weather events through early warning systems	… I can create effective plans to protect people, animals and infrastructure against natural disasters in advance
9	Civil Protection Officer/ Emergency Response Team	… to know immediately why a warning has been generated, with clear visualization of low and high risk areas	… I can create an effective emergency response plan accordingly
10	Urban Planner	…. to be able to easily make changes to the digital twin model	…. so that I can investigate the impact of different interventions/mitigations as well as examine the impact of any potential changes to infrastructure
11	Urban Planner	… to know the projections of coastal erosion and SLR under different scenarios as part of digital twin model	… I can make futuristic 30-year or 100-year plans under all the plausible climate scenarios accordingly
12	Score Project Officer/ CCLL Leader	… scenario simulations on a short-term scale (near real time) e.g.: what are the expected impacts in a near real-time on the territory if starts/stop to rain.	… I can help Civil Protection Officers, Emergency Response Teams and Municipalities to interpret the results and communicate the uncertainty
13	Civil Protection Officer	… to know the 24/48-hour scale (forecasts) and the 3/6-hour scale (now-cast)	… the system can classify the physical models result (affected by uncertainty) assigning a probability to each scenario and to the relative early warning procedures and the system can integrate the sensors network measures to identify a unique "most likely" scenario and suggest an eventual disaster management procedure

14	Civil Protection Officer	... now-casts to be updated as soon as input data is available, incorporation of geo-referenced citizen images and the immediate integration of reliable sensor data into the visualisation	... We can use the data with high level of confidence in making our emergency response plans and policies
15	Citizen	... the ability to comment or upload the latest information related to extreme weather events in my locality	... I can help increase the accuracy of the available information as well as assist other citizens/stakeholders with their emergency response

2.5. Selection for the first DT development

For DT we started creating a mind map (Figure 8) with the different dimensions based on the CCLL questionnaire data gathered in WP2 from various stakeholders, which will be helpful in policy making for each CCLL coastal cities. This mind map will be edited and used throughout the project in order to define the next set of user stories to be tackled by development.

Each set of user stories will be detailed further and together with technical requirements and information related to datasets and sensors to be used from the users towards the development team.

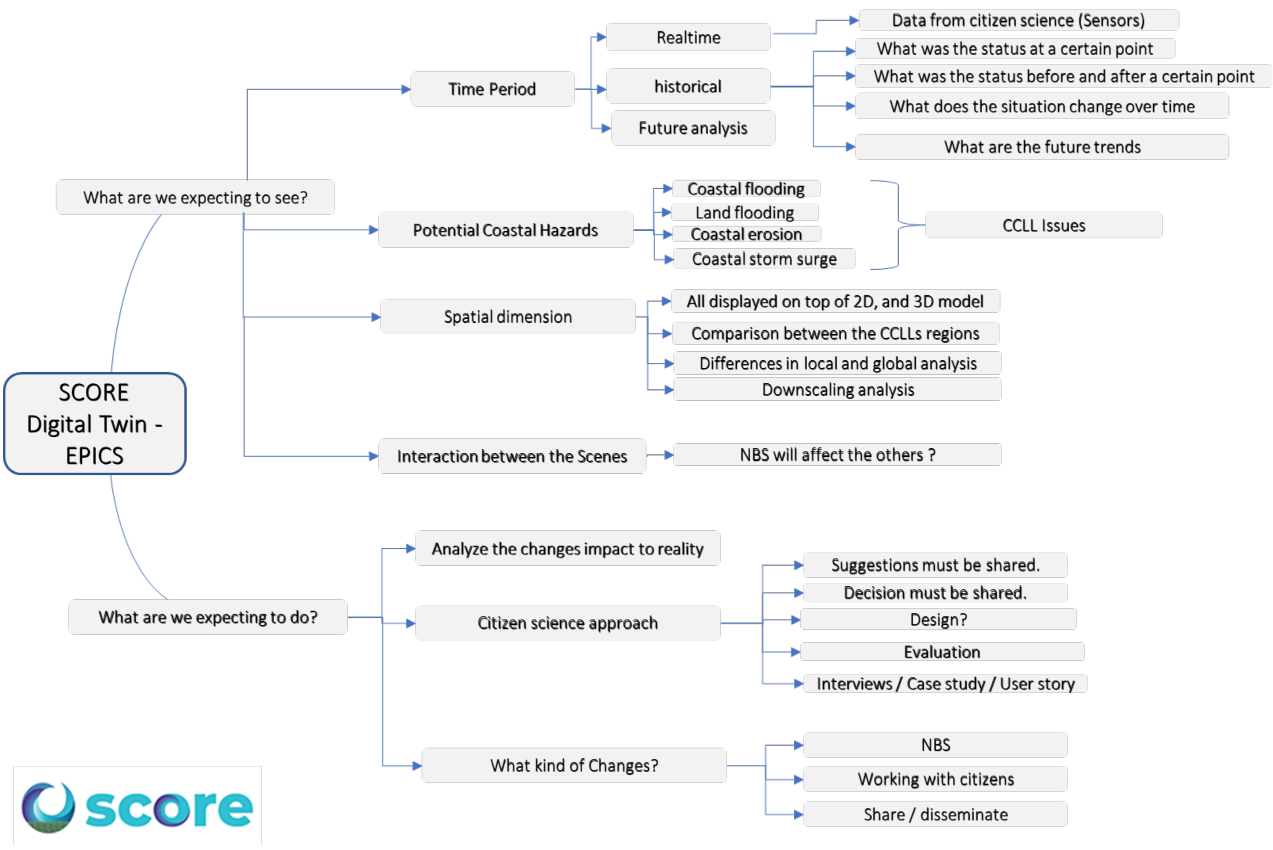

Figure 8 Epics Mindmap

2.6. Concept of operation

A "need" is essentially anything wanted or a condition in which something is necessary. In general, we use the term "need(s)" to refer to items that are necessary for an organism to survive. For instance, food, water and safe environment are considered to be fundamental human necessities, and thus can be referred as "needs". Instead, the "requirements" are the actions necessary to meet a need or accomplish a goal. Users provide functional and non-functional requirements, which form the basis for the project. Functional criteria are linked to the capacity to directly assist the users' mission/task achievement (features, components, etc.). Performance/functional requirements are those that develop as system requirements to meet non-specific demands and are often implicit and technical in nature (e.g., quality of service, availability, timeliness, and accuracy).

SCORE works closely with users to observe, discuss, and understand their needs, as well as analyse feasible solutions to meet them. It is widely accepted that stabilizing requirements early in the project's life cycle, where possible, help later project work and decreases risk greatly.

Preliminary results from questionnaires were evaluated and a number of key requirements were extracted and discussed in the frame of WP8 (Development of integrated early warning support and spatial digital twin solution prototypes) which provided a valid insight into requirements and expectations of the end-users. The requirements for the EWSS and DT platform are presented with more details in the next sections.

Moving forwards, the portfolio of use cases presented in previous section, will have to be validated through WP2 workshops to focus on developing selected ‘feasible’ use cases. The feasibility of developing each use case will be determined, primarily based on two factors:

- Whether there is an active interest in the use case amongst end-users;
- Whether the use cases is feasible for the EWSS and DT platform, from a technical perspective.

3. System requirements

3.1. Overview

The SCORE project involves the development of two modules. The first one is a Digital Twin that simulates the behaviour of the coastal/urban environment when changing the climate conditions. Moreover, it allows to change the urban environment to study solutions to increase the resilience of the city/coast to the effects of CC. A second module called Early Warning System identifies dangerous situations for the users having in charge of any emergency management, to be promptly informed when changing weather conditions.

The project also involves the development of a GIS-based interface that can display the map of the coastal city monitored by the system together with a real-time representation of the weather as well as the sensors used to support the weather and hydrogeological models of the environment.

In this context, the project develops in two uses:

- Short-term forecasts on the impacts of weather conditions at local (urban) Scale
- Environmental Analysis

The Short-term forecasts allows real-time monitoring of the environment under observation, integrating environment and weather models with real-time data, gathered from the installed sensor networks. The Environmental Analysis mode, using the same models implemented for the Short-term forecasts on weather conditions, allows Users to modify the urban environment and/or the weather conditions to analyse and measure the resilience of the environment in different conditions. Through these simulations the DT is able to support urban space planners, by the design of interventions to improve resilience, as well as to improve the awareness of politicians and citizens, and to create a support system for the training of rescuers in the field of civil protection.

3.2. Technical

3.2.1. Sensor Technology

A vital input to the development of the GIS based early warning support and digital twin platform is the data output from low-cost sensing technologies to monitor the climate induced coastal hazards. A catalogue of these low-cost sensing technologies will be developed and consequently updated as part of WP4, which will actively engage citizens and stakeholders in the monitoring process of the specific hazards in their respective CCLL's. The GIS based EWSS will facilitate the integration and clear visualisation of the temporally (including real time) and spatially distributed data extracted from the institutional as well as low-cost citizen science sensors to visualise the respective CCLL in its current and future states as the data from the sensors can be integrated with weather forecast information (available through WP5) and with climate projections (WP3). In addition to the data from these low-cost sensors being reliable, the durability of these sensors is paramount to ensure that it lasts beyond the project lifetime. This would imply that the data from these sensors can be indefinitely (until the next maintenance cycle) fed into the tools developed as part of WP8 to minimise replacement, recalibration, cost and disturbance for the intelligent instant monitoring and control of climate resilience in the European coastal cities. Table 3 shows the sensor technologies utilised to measure specific parameters in different CCLLs' along with the citizen science activities and different hydrodynamic models to better quantify the hazards.

Table 3: Sensors, models and citizen science activities to monitor the specific forcing agents of the coastal hazards in the SCORE CCLL's

No	City	Parameters	Sensors	Citizen Science	Models
1	Sligo	Wind Precipitation Sea level	Wind sensors Rain/Tip gauges Webcams	App for coastline monitoring App for flood early-warning in urban areas Citizen meteo stations	Hydrological model Meteorological model Oceanographic model
2	Dublin	Wind Precipitation Sea level	Wind sensors Rain/Tipe gauges Webcams	App for coastline monitoring App for flood early-warning in urban areas Citizen meteo stations	Hydrological model Meteorological model Oceanographic model
3	Massa	Waves effect in shore (webcam) River flow rate related to floods (hydrometers) Rain flow related to floods (radar, pluviometers, rain gauges)	Webcam Hydrometers Rain Gauges	Geo referenced photos/videos both during (1) storms and (2) river flow Amateur rain monitoring with rain gauges	Long term model for coastal erosion Hydrological model related to floods Storm surge (XBeach)
4	Samsun	Wind Precipitation Sea level	In situ and satellite tools Radar products Automatic Meteorology stations Data	Geo referenced photos/videos both during (1)storms and (2)river flow Amateur rain monitoring with rain gauges	Wave prediction model Hydrological model related to floods Storm surge (XBeach)
5	Benindorm	NA	NA	NA	NA
6	Basque Country	Coastline evolution Rainfall Sea level evolution	satellite images SmartLNB Depth gauge	Georeferenced images of coastline (mobile phone) Ensuring accurate referencing of 1. -	Storm surge model Drainage network model

				beach markers get removed – needs some thought Low cost raingauges	Hydraulic river flooding model
7	Gdansk	Ocean water level Rainfall River water level	Cameras/Pictures Sensors of opportunity – low cost run sensors – ex. Similar to automotive radars	Tourism impact on buildings heritage Monitoring of the urban draining system Traffic monitoring during flooding	Atmospheric Hydrological Tide model
8	éPiran	NA	NA	NA	NA
9	Oeiras	NA	NA	NA	NA
10	Province of Barcelona	Water level in manholes Rainfall Sea level evolution	Water pressure sensor SmartLNB Depth gauge	Georeferenced images of coastline (mobile phone) Map of manholes in city and app to allow citizens to select one and alert that it is blocked/flooded Low cost rain gauge campaign	Storm surge model Drainage network model Hydraulic river flooding model

3.2.2. Short-Term Forecast

The Short-Term Forecast mode allows the monitoring of the environment when the weather conditions change for short periods. The city's Digital Twin works in symbiosis with the models chosen to represent the environment, e.g., the hydrological model of the area, in order to evaluate the consequences on the coastal city following sudden changes or worsening weather conditions.

Figure 9 shows the modules involved and their data flow in the real-time monitoring mode.

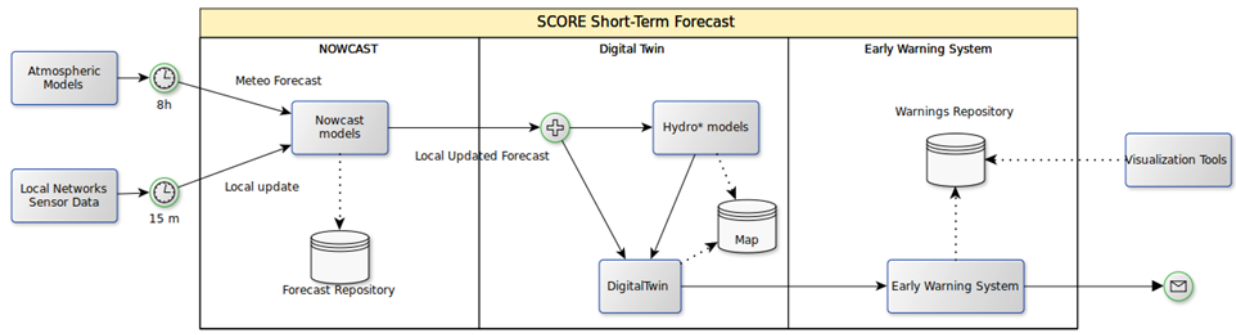

Figure 9 SCORE Short-Term Forecast

The pipeline input are the weather forecast and the values of the local sensor network of the city. On the other side, the output is a possible alarm signal following a weather forecast considered dangerous. The steps in-between represent the following expected features:

- Nowcast
- Digital Twin
- Early Warning System

Nowcast

The purpose of the Nowcast functionality is to "localize" the weather forecast through the correction obtained through the integration of real-time sensor values from the local sensor network from the city. Furthermore, since the weather forecasts are updated at time intervals longer than the time sampling of city real-time sensors, a local correction of the forecasts should be able to rapidly integrate this data. This procedure could be based on the introduction of neural networks that allow a forecast of the time series linked to the city sensors. This system generates a local weather forecast "strengthened" by localized forecasts through the expected trend of local weather sensors. It is planned to use these forecasts to measure the error and eventually to provide training data for a subsequent learning phase of the neural networks.

Digital Twin

The next stage is powered by localized weather forecasts. The physical models will assess the impact on the environment of the forecasts received, evaluating the behaviour of the hydrological basin and its variations. These changes are communicated to the Digital Twin which, in turn, will assess their impact on the city. It should be noted that the Digital Twin stage is composed of various models which, integrated together, simulate the expected behaviour of the natural environment. These models need environmental maps (represented by the Map module in the diagram above) called Digital Terrain Model (DTM) to access structural information of the urban environment, and reservoir that should be integrated in order to provide a unified representation.

As an example, let us consider the case of a canal running through an area of the city. If the localized weather forecasts indicate a consistent amount of rainfall nearby the canal, the Digital Twin can integrate this data with the speed and the volume of water predicted by the hydraulic and hydrological models in order to improve knowledge of areas subject to pluvial flooding (like road underpasses, etc.)

Early Warning System

The environmental changes provided by the Digital Twin are received by the Early Warning System module which, based on its critical issues configuration, will generate alarms to be displayed through a Visualization Tool. At the same time, alarms are sent to users and/or to designate organizations for their management. The alarms/warnings generated are also stored in a repository for every possible use. For example, the Visualization Tool will access the repository following its own logic when a new alarm or warning is available.

Following the example of the previous paragraph, if the Digital Twin foresees the flooding of some areas, one of these involving the presence of underpasses and/or roads, the Early Warning System module will generate the Warning only for the defined involved area.

3.2.3. Environmental Analysis

This offline mode allows the monitoring of the environment in back test mode to measure both the reliability of the implemented models and the resilience of the environment under modifications of the weather conditions and/or the urban infrastructure as shown in Figure 10.

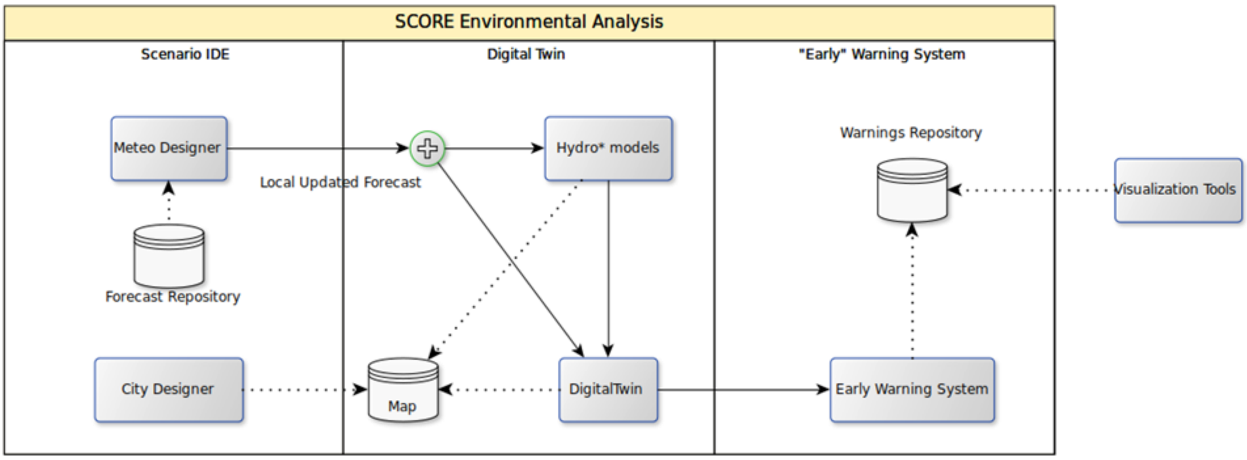

Figure 10 SCORE Environmental Analysis

The Environmental Analysis pipeline traces the Short-Term Forecast scheme discussed before, see Figure 10. As a comparison, only the input data source has been changed, replacing the Nowcast functionality with that of Scenario IDE (Integrated Development Environment).

The Scenario IDE contains two Designer modules for the weather and for the modifications of the urban infrastructure, respectively. Using the IDE, Users can change the working conditions of the environment, the weather conditions, also replicating critical conditions recorded in a past situation, on a new urban organization to verify how the hydrological and urban models changes the behaviour with the new working situation. It is important to notice that the Digital Twin involved in this procedure is the same defined and involved in the Short-Term Forecast. In this context, the Early Warning System module is not linked to any alarm management system.

3.2.4. Models

The Digital Twin allows the creation and maintenance of virtual representations of real-world environment and its processes. It receives and interprets data flows produced by distributed Internet of Things (IOT) sensor devices installed in the city and in its surroundings, but it is fundamental that the Digital Twin implementation shall be based on a set of physical models describing the evolution of the natural environment. Moreover, the real representation of the world is strongly linked with the City Digital Twin and cannot be considered as a different module in the virtual city representation. All the weather downscaling process, starting with the localization of global weather forecast, integrated with the real sensor data, is the fundamental process used to create the proper working environment for the Digital Twin. For these reasons, all physical models together with the virtual city model shall be considered in the domain of the Digital Twin.

An important aspect to highlight is how the models involved are strongly connected. The Figure 11 shows the connections between the models and how the flow of information moves among them.

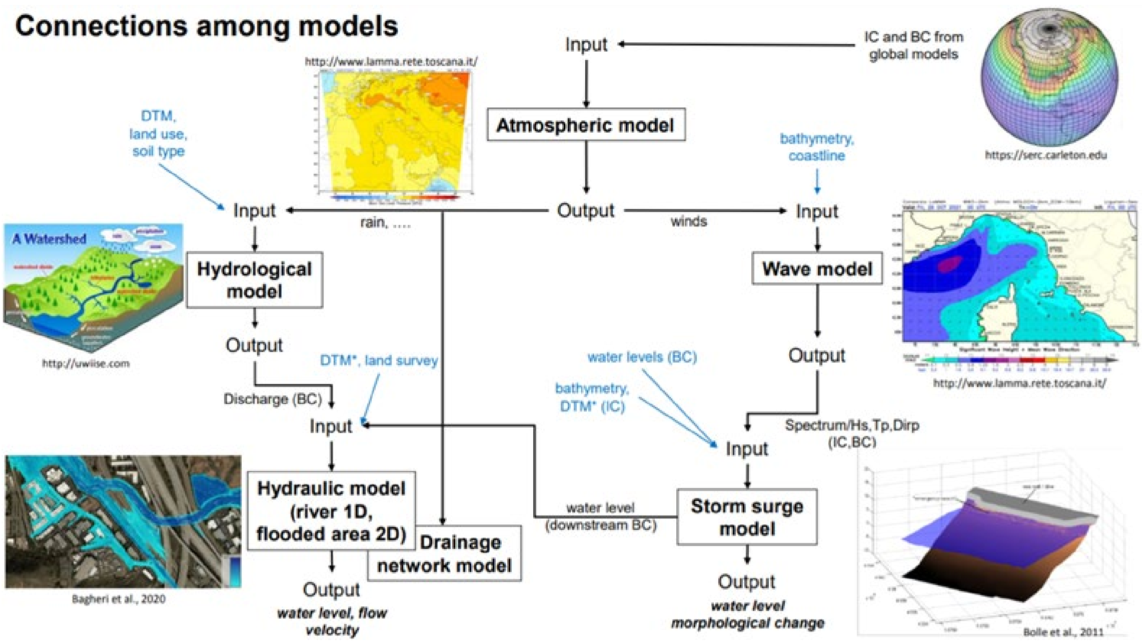

Figure 11 Connections among models

Besides the formal description of the models, (additional information about the schema above can be found in the deliverables and outcomes of the WP3) a general consideration is that the results of each model are strongly dependent from their input and from the description of the region where are operating. Each input is the result of a previous model which operate on a different set of input, starting from atmospheric model and down to the local region.

The SCORE Digital Twin implements all the considerations introduced above. The schema in Figure 12 shows additional details about the Digital Twin introduced in previous chapter.

From a functional point, the schema appears as a new pipeline consisting of four stages, where each one is a physical model and the last is the city model. The city model receives the forecast computed from previous stages and computes the consequence on the urban environment. Each model works on a digital representation of the terrain, i.e. the DTM, which describes in details the required terrain information (different for each physical model), and the localized weather forecast powered also by the local sensor network.

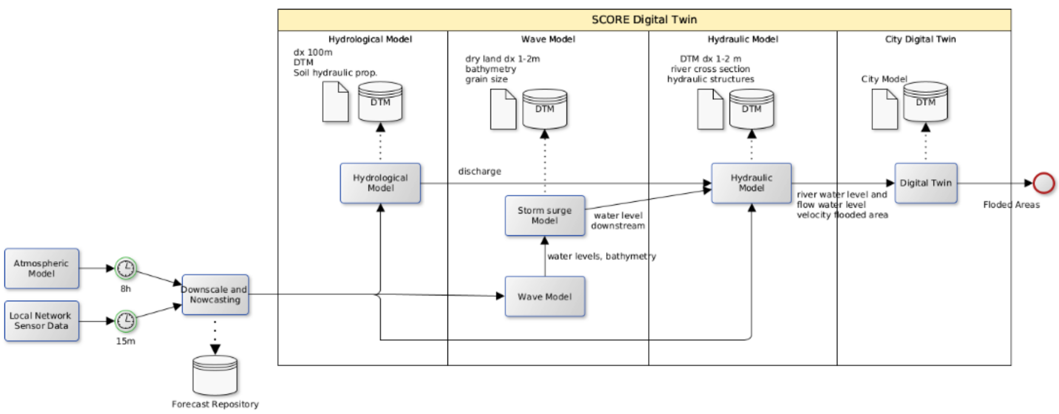

Figure 12 SCORE Digital Twin

Localized forecast and local sensor data are processed by the Hydrological model, Wave model and Hydraulic model to identify river water level, the flow of water and the velocity of the flooded area. The City Model receives this information to elaborate the impact on the city.

Finally, the short-term forecasts and the environment analysis mode uses essentially the same the SCORE Digital Twin with the same pipeline and with the same physical models (Figure 12). When the SCORE platform is used in the short-term forecasts it is important to emphasize that only the weather forecast is a dynamic input for the SCORE Digital Twin, while the DTM used by models must be considered as a static and unchangeable input. Therefore, the Early Warning System needs to use the most faithful representation of the territory where only weather conditions can change.

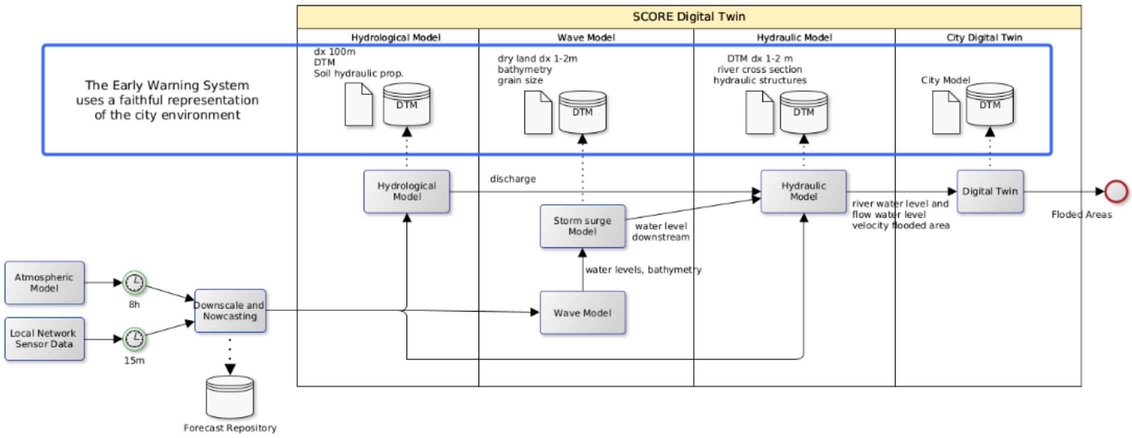

Figure 13 SCORE EWSS and DT

Instead, when the Digital Twin is used to analyze the territory and to plan changes on it, the physics models can be fed both with representations of the territory modified from the original one, and with "synthetic" weather conditions designed to stress the intervention on the territory to understand its resilience

3.2.5. Computing capacity

The physical models require large computing capacity when running. Moreover, since the time constraint is a strong requirement for the Early Warning System, it is important to define the time interval for which the output of the models is useful, or it is generated too late. The correct trade-off must be found between the accuracy of the results and the time needed to obtain it. For this reason, the comprehension of the necessary timing to manage the possible warning in an urban area represents an important step. At the same time, the analysis of the computing power required to support physical models to generate output in a time to be managed is also crucial.

In this context, when the time required for models to generate output does not comply with the requirements of the Early Warning System, a countermeasure must be defined in advance. A solution to be used in parallel to the physical models when they required longer time to support the Early Warning System is based on software emulation of the real models implementation. This emulator must be able, in a short time, to provide an approximate result that will be validated by the real model and eventually used to improve the accuracy of the emulator itself. Among the possible approaches, the use of neural networks or similar will be evaluated. In the same way, a possible solution could involve the use of input downscaling and output upscaling models in order to reduce the execution time of the physical models.

3.2.6. Early Warning System Strategy and Classification

The main strategy implemented in the Early Warning System is the formal definition of a set of possible scenarios that can be identified in the urban areas when weather changes. As described in the previous paragraphs, the Digital Twins implements a physical models cascade (meteorologic to hydrologic and marine to hydraulic) and performs a further step, mapping a certain scenario to the effects on the city functional assets and infrastructures, as shown in Figure 14.

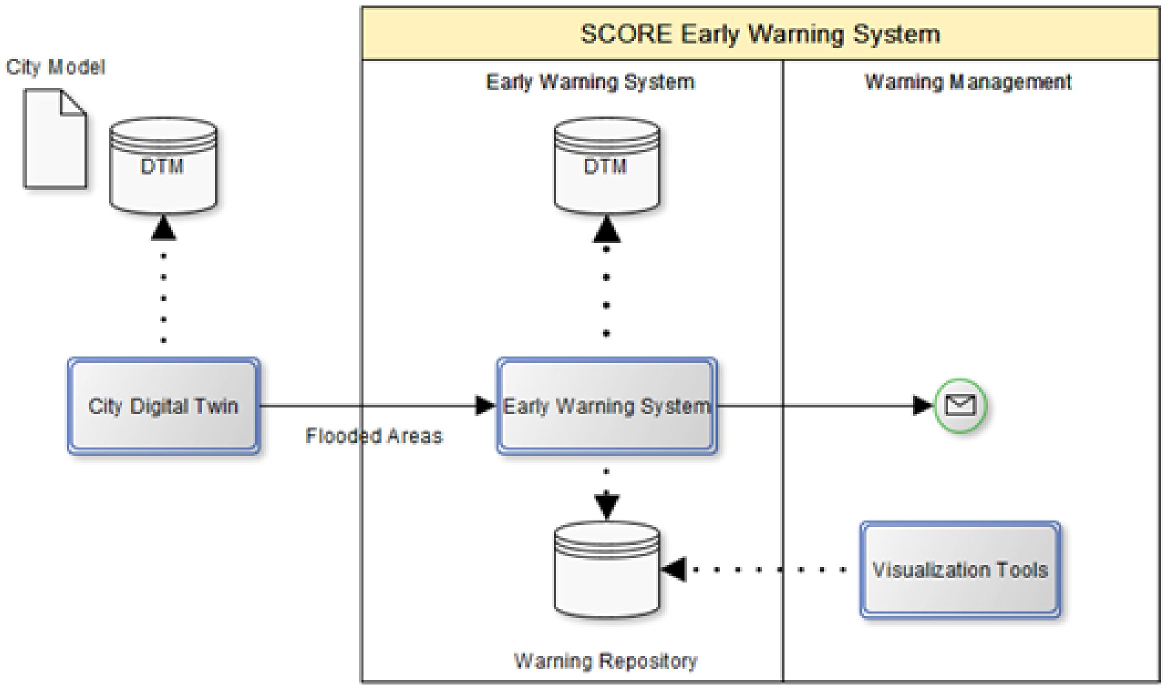

Figure 14 SCORE EWSS

These operations should be performed with respect to two different time scales:

1. 24h to 48h forecasts: the system provides a classification of the outcome of the physical models taking into account the uncertainty of the results and assigning a probability to each scenario and to the relative early warning procedures;
2. 3h to 6h forecasts: the system should integrate the sensors network measures to identify a unique and most probable scenario and suggest an eventual disaster management procedure.

The need to define a set of reference scenarios allows to define a clustering process on the possible output of the Digital Twin, with a classification of the possible situations to manage. In other words, the set of all possibile outcomes of the DT can be discretized in a relatively small number of warning situations and hence to characterize each scenario from a reduced number of relevant aspects. In these regards, based on a list of possible critical areas mapped on a custom urban DTM, the Early Warning System generates possible warning situations identifying the reference cluster using the scenario received from the City Digital Twin.

3.2.7. Modelling approach

The modelling is based on the PowerSchedO framework by MBI srl. PowerSchedO is a framework designed to define mathematical problems with an object-oriented approach. It is made of an abstraction stack composed by four abstraction layers used to translate the Business world into a mathematical problem.

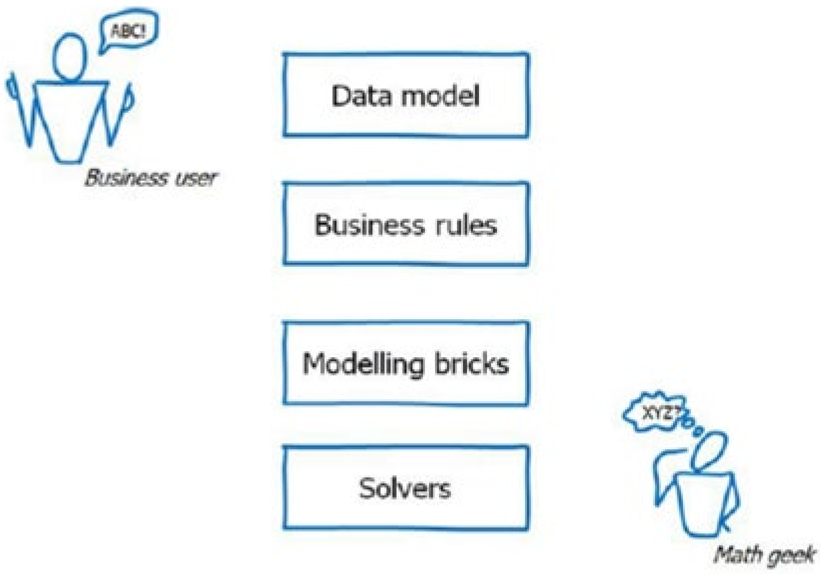

Figure 15 Modelling approach

The aim of each layer is to translate the data, the vision of the world of the upper layer, into a vision of the layer below, to prepare the "translated" data for the mathematical solver. This is needed because the business user perfectly knows the rules and the data moving in the business world, but the information present in the data and in the related business rules, need to be arranged into the appropriated mathematical set of rules, constraints, and solvers as shown in Figure 15.

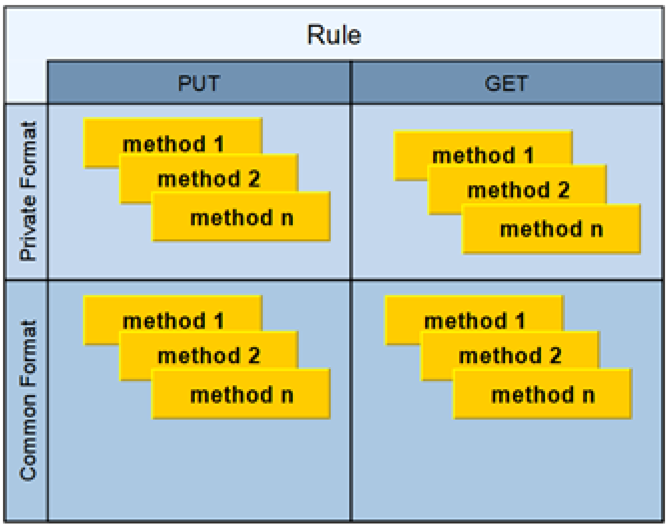

Figure 16 Rule

Each layer is than composed on set of rules, where each rule represents a step of this translating process. The Rule can be divided into two flows: one flow is responsible for providing a way to the underlying level, and the other one is used to move information to the upper lying abstraction, as we can see in Figure 17. The methods implemented in each Rule and in each flow have the aim to perform each step of this transformation. Moreover, the rules are executed sequentially in a well-defined order as shown in the beginning of this paragraph defining the "translating" process as shown in Figure 16.

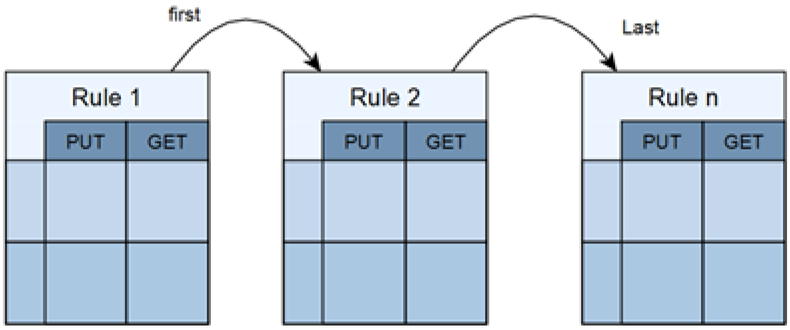

Figure 17 Order of rules

The modelling approach described provides a method to model several and different Business worlds (Figure 18). In each layer, the data is transformed to extract the right information for the involved layer, with the goal to provide the field for the next layer. Finally, the Solver receives the information structured for the kind of problem it has to solve.

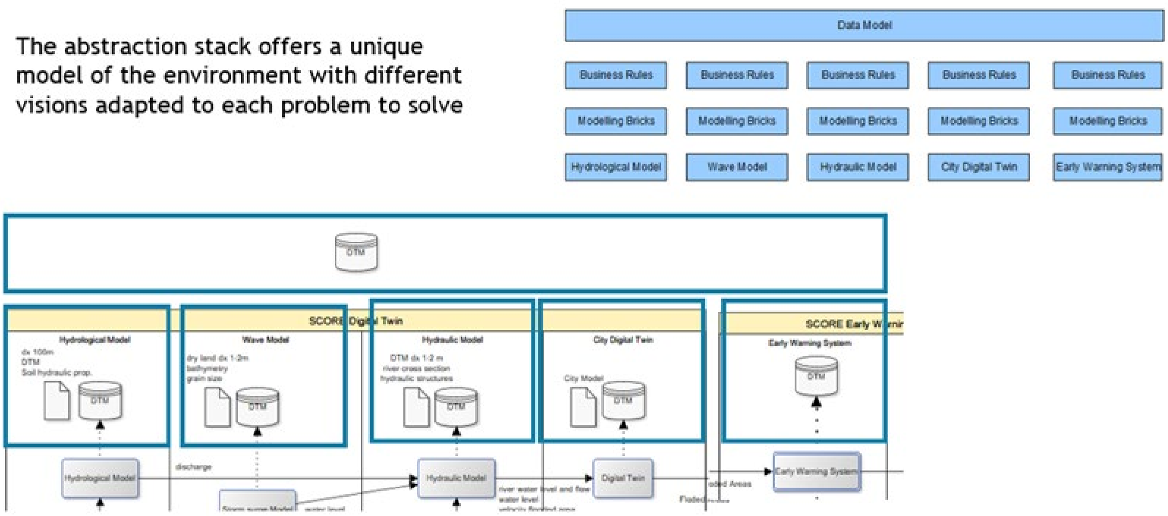

Figure 18 Business rules

Within the SCORE context, this framework represents a reliable way to structure and manage both the DT and the EWSS discussed earlier. The full data model is therefore built as stack of business rules and modelling bricks associated to each particular module, so as to define a structure allowing to connect and relate them (Figure 18).

3.2.8. Visualization

The visualization tools integrate a GIS-based platform at their core. This geoinformation system and map-based interface showcases data to visualize, compare and analyze measurements on real-time monitoring and short-term forecasts of weather and environmental conditions within the scope and geographic area of the different CCLLs. Also, this platform should enable users to interact with city virtual representations and analysis (Digital Twin) of the real-world environment and its processes. The Digital Twin computes various models which, integrated together, simulate the expected behaviour of the natural environment, as well as user-designed interventions in real scenarios.

Thus, this platform introduces data visualizations, mapping capabilities and 3D visualizations to explore the outputs from smart sensing technologies, citizen sensing (data and media content), and different climate, hydrological, marine and urban-scale (e.g., hydraulic) models. Also, it presents data to showcase and create advanced environmental analysis, and early available warnings, alerts and affected areas related the coastal hazards and risks.

Several data visualizations elements are provided in accessible way to see, understand and estimate trends, outliers (e.g., as alerts), patterns in data, and the environmental impacts created by different data-driven EBA solutions. Those elements include time series, timelines, indicators, charts, graphs, interactive tables and visualization plots and dashboards. But also, base maps (e.g., road networks, topographic data, land cover), heatmaps, and color-coded maps showing important environmental data (choropleth maps) such as flooded areas, or low and high risk areas. Also, maps with codified regions based on a chromatic index associated to a monitored condition or variable, for instance, the incidence level of a forecasted meteorological condition, potential coastal hazards and risk levels, etc.

Using the features introduced above, identified users' needs will be addressed by enabling actions and tools such as:

i) spatio-temporal visualization of variables representing different forecasts and atmospheric, environmental and marine conditions in local and regional areas;

ii) selecting and exploring data streams from sensors, and integrate different geographic features on top of base maps and interactive virtual city models;

iii) visualizing and comparing current situations and differences in local and global analysis, and between the CCLLs;

iv) identify, visualize, and be informed when a potential risk, extreme weather events, and alerts have been generated;

v) to know the projections of coastal hazards under different scenarios as part of a Digital Twin model;

vi) to create scenario simulations on a short-term scale (near real time) for environmental analysis, e.g.: what are the expected impacts in a near real-time on the territory if starts/stop to rain.

Finally, the scenario-based simulations for environmental analysis should help to show and monitor the environmental impact for new or existing EBA solutions, or to perform different risk simulations at urban scale based on different data integrations and visualizations. This tool based on a spatial context and using visual dashboards and storytelling helps communicate design actions and alternatives that are data-driven, visually impactful, and interactive.

3.3. Non-technical

3.3.1. Security and access

The system should be secure, which means that the user must be satisfied that the data obtained from all CCLLS in all WPs is trustworthy and that no one can tamper with the data, models, sensors, or other system components. By limiting and managing access to the system, the system integrity will be preserved to the greatest extent feasible. Access to findings must also be restricted to avoid the dissemination of erroneous information; often, an experienced operator is required to accurately estimate danger levels, even if the interface is clear and simple to use. Moreover, computer systems should be protected against tampering or hacking; they should also be safe (against hazards) and have a secure or backup power source. Buildings must be accessible in the event of a danger, and workers must be able to work there (think of heating, food, possibility to stay overnight, etc).

3.3.2. Ethics

The SCORE project is committed to ethical research practices and intends to strengthen the consortium members' scientific, technical, and sociocultural capacities, as well as the communities they serve. The ethical section is covered by the WP10 lead by the main partner IT Sligo, Ireland. The first delivery of the ethics policy is available online [19]. The document has been disseminated democratically to all consortium members and their internal Ethics Committees and Data Protection rules. To accomplish the SCORE objectives, several activities and events are proposed, including the collection of general personal data from citizen scientists participating in the Coastal City Living Labs events (WP2) and Developing and Deploying Coastal Risks Early-Warning Sensing Technology events (WP4), as well as the socioeconomic evaluation of the EBAs and SCORE solutions (WP7). Solidarity and inclusion are strongly valued among a diverse group of citizen scientists, local government, and the researchers participating. SCORE will incorporate all ethical standards to protect participatory engagement with citizen scientists from any potential legal or ethical implications or liabilities, by ensuring that all technological and human resource standards are consistently followed and enabled at the start of the SCORE project through educative and informational events.

4. Conclusions and recommendation

This document details the methods and functional requirements for the development of a GIS-based interface that can display the map of the coastal city monitored by the system together with a real-time representation of the weather as well as the sensors used to support the weather and hydrogeological models of the environment.

The first section of this document discusses digital twin and early warning approaches, as well as examples of how they have been employed in various past, present, and future projects. Additionally, this document explains the relationships between WP8 and the other work packages and how data would be gathered from all work packages in order to construct the early warning system support technology.

The second part of the document is based on input from end users received through WP2's questionnaires, and sprint workshops. Moreover, it contains a set of use cases that will be utilized to establish the needs, demands, and associated functionalities for the development of GIS- based early warning system support using digital twin technology for all CCLLS.

The third part of this document is then devoted to the definition of the system requirements and outlines the essential features of the digital platform. The GIS-based EWSS and the DT modules are framed in an object-oriented approach in which all the relevant building blocks of the city models have their corresponding representation in the virtual environment. Within this platform, sensor data is integrated into physical models and weather forecasts in order to obtain reliable local short-term forecasts which, in turn, are connected to the EWSS. In addition, the same DT is intended to be used also for environmental analysis allowing to measure the resilience of the environment in response to modification of both the urban system or the climate conditions.

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