Urban Data Governance

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Urban Data Governance: an interoperability-based approach for monitoring natural threats at different geographic scales, through Smart City Platforms

Arianna Brutti[1], Antonio Di Pietro[1], Angelo Frascella[1], Sonia Giovinazzi[1], Cristiano Novelli[1], Gianluca D'Agosta[1], Stefano Pizzuti[1], Maurizio Pollino[1], Ane Ferreiro Sistiaga[2], Saúl Buitrago[3], Iñigo Lopez-Villamor[4], Simone Murazzo[5], and Gian Marco Revel[6]

[1] ENEA, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Italy
[2] CYPE SOFT SL, Spain
[3] Delft University of Technology, Netherlands
[4] TECNALIA, Spain
[5] Live Information System SRL, Italy,
[6] Università Politecnica delle Marche, Italy

Abstract. Monitoring, preventing and managing the impacts induced by extreme natural events requires the use of multiple and different Information Communication Technology (ICT) tools and technologies capable of collecting and processing data from various sources, and supporting public stakeholders in the planning and implementation of prompt actions. In this perspective, the availability of platforms able to harmonize, integrate and manage heterogeneous data and to create new knowledge, can constitute a valuable support. This article presents some preliminary results from the EU-funded MULTICLIMACT project, part of which is defining a reference model for customizing and adopting the ENEA Smart City Platform to inform on the severity and extent of possible impacts induced by natural threats and on possible resilience strategies. Towards that the Smart City Platform enables the interoperability between heterogeneous digital solutions monitoring natural threats at different geographic scales.

Keywords: Interoperability · Smart City Platform · Ontology · Specifications · Smart City · Natural threat · Earthquake · Flood · Heat waves · Well-being · JSON.

1 Introduction

Natural and man-made hazards are increasingly threatening our cities and communities. It is therefore imperative to provide readily accessible information and know-how to public authorities and stakeholders on the possible impacts that such hazards might induce on different exposed elements, as well as on the opportunities of implementing resilience strategies to mitigate impacts, to adapt to long-term threats and to promptly recover and thrive in the aftermath of crisis. The on-going digital transition is posing an unprecedented opportunity towards that; cities can be digitally empowered with low-cost sensors, smart collaborative technologies, interoperable platforms that, thanks to open-science algorithms and applications, allow democratizing access to data and information and fostering knowledge [8]. The possibility to monitor in real time natural threats at different geographic scales within the city enables informed, aware and participatory decision making processes, thereby enhancing resilience.

Several definitions of resilience have been applied to urban systems and cities. The United Nations [11], defines resilience as "the measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability" and a resilient city as the one that "valuates, plans and acts to prepare and respond to threats – natural and human-made, sudden and slow-onset, expected and unexpected – in order to protect and improve the lives of people, secure development gains, foster environment, and drive positive change" [13].

Technology, data-driven decision-making, and citizen engagement can provide a substantial contribute to build resilient cities that can withstand and recover from challenges effectively. This ability aligns with the definition provided by the United Nations Economic Commission for Europe (UNECE) for a smart city, which is described as "an inclusive, safe, resilient, sustainable, and connected city for all" [12].

In this context, the availability of multipurpose frameworks that can interconnect various heterogeneous software tools and solutions is crucial. These frameworks ensure interoperability, which is the ability of two or more networks, systems, devices, applications, or components to exchange and use information securely, effectively, and with minimal inconvenience to the user[10].

The Smart City Platform Specification and the platform based on this specification, presented in this paper, aims to: i) provide a replicable and sustainable methodology based on public specifications for interoperability communication between technological solutions, aimed at avoiding vendor lock-in; ii) interconnect resilience and smartness features both essential for urban systems; iii) unequivocally define Key Performance Indicators (KPIs) and iv) harmonize and democratize access to KPIs and data, making them comprehensible and accessible to all. [14].

The paper is organized as follows: Section 2 presents the problem and related works in the area. In Section 3, the Smart City Platform Specifications for Interoperability Layer for monitoring natural threats are presented. Section 4 outlines case studies across different geographical scales from the MULTICLIMACT project, demonstrating the implementation of Smart City Platforms Specifications for monitoring natural threats. Finally, Section 5 discusses conclusions and ideas for future work.

2 Related works

The world is becoming increasingly smarter. We are building smart homes within smart buildings, connected by smart roads, all surrounded by sensors that can analyse air quality. Here people, equipped with smartphones, drive smart cars. All these smart devices are interconnected within a smart city.

The development and proliferation of such technologies presents new challenges (such as the need to avoid the vendor lock-in and to implement the data integration and harmonization), but also significant opportunities: one major opportunity is the ability to collect data to enhance security and manage natural hazards. However, to fully exploit this potential, it is crucial that all the collected data can be exchanged and readily used for forecasting and managing natural hazards. In other words, interoperability is essential.

The study [2] provides a literature review about existing research approaches in ICT for Disaster Risk Management. It highlights that "most of the selected studies focus mainly on delivering solutions regarding the prevention or reporting of a natural disaster, whereas a holistic approach is not examined" and that "this barrier in data sharing and interoperability" can hamper the "presentation of information to decision-makers".

Similarly [9], starting from a literature review, emphasizes that data interoperability in disaster risk reduction "remains a challenge due to a number of barriers that preclude exploitation of available data for disaster risk reduction before, during or after a hazard has materialized into a disaster". This paper identifies the following barriers to data interoperability:

- the high number of actors involved (civil protection, firefighters, healthcare services, municipalities and non-governmental organizations among others);
- lack of standardization in data collection, processing and distribution;
- the fact that data are collected, processed and distributed by a wide range of actors using different routines, standard and requirements.

The study [1] proposes an interoperability assessment approach "to identify the potential inter-operation in a disaster response management environment". By identifying and weighing key interoperability criteria, the framework helps entities to understand their current capabilities and areas needing improvement, thus enhancing their ability to manage and respond to crises effectively. So, this approach helps in identifying gaps, but does not arrive at a complete solution.

The issue of establishing an interoperability framework for Emergency Management Systems (EMS) across different European countries involves not only diverse IT solutions but also the variety of languages spoken in Europe. Paper [5] presents a software solution leveraging semantic and mediation technologies to tackle these challenges. The proposed solution utilizes a common, modular ontology that accounts for cultural and linguistic differences, and is built on a service-oriented architecture to ensure data interoperability. However, neither this paper address the challenge of integrating data from various sources.

As, at the best of our knowledge, there appears to be no specific solution available, we will expand our focus to consider the general approach needed to achieve data interoperability.

Interoperability is a complex attribute influenced by numerous factors, including functionality, business processes, human interaction, trustworthiness, timing, data, boundaries, composition, and lifecycle, distributed across different interoperability levels. Various layered stacks exist for interoperability, each differing in how they group concepts at each level based on the model's goals, though the underlying concepts are largely similar. From these, we can define the following layered stack: Collaboration, Functional, Semantic, Information, Communication [15].

Additionally, achieving interoperability requires on one hand the development of protocols—sets of communication rules—that comprehensively define all aspects, from the communication channel to the meaning of the exchanged data but on the other hand it also requires system stakeholders to agree to use these protocols [3].

From this, several key principles of data interoperability can be identified. [7]:

- Avoidance of semantic ambiguities in specification definitions to ensure application interoperability.
- Clear definition of the specification lifecycle, considering every stage (e.g., definition, implementation, adoption, configuration, etc.).
- Ensuring the usability of the specification for various users, including technical experts, domain experts, management personnel, and end users.

To address the challenges associated with implementing data interoperability and dismantling silos in natural threat monitoring, it is crucial to adopt a multi-tiered strategy that adheres to the following fundamental principles.

ENEA laboratories CROSS (Cross Technologies for Urban and Industrial districts) and SCC (Smart Cities and Communities) have developed, in the context of Italian National Research programs, a solution for interoperability of data coming from the different smart city applications: the "Smart City Platform Specification (SCPS) for Interoperability Layer" [4]. It is a set of specifications tackling the problem from the above explained perspective; such a solution has been adopted as the reference architecture for defining the reference model for implementing Smart City Platforms for monitoring natural threats at different geographic scales.

3 Context, objective and approach

3.1 Context and objective

The reference model for implementing interoperable Smart City Platforms for monitoring natural threats at different geographic scales has been designed in the context of the EU HE MULTICLIMACT project.

One of the objective of this project is to develop a mainstreamed framework and a tool for supporting public stakeholders and citizens to assess the resilience of the built environment and its people at multiple scales (buildings, urban areas, territories) against locally relevant natural and climatic hazards, as well as to support them to enhance their preparedness and responsiveness across their life cycle. In particular, the main output of the project will be a toolkit of Design Practices, Materials, and Digital Solutions, enabling users to easily estimate the impact of their implementation on the resilience of the targeted asset, integrating a multidisciplinary approach combining socio-economic, life, engineering, and climate disciplines. The Digital Solutions will enable the monitoring, detection of, and response to critical situations, improving the protecting role of the built environment for people safety and quality of living. Specifically, the following natural hazards are analyzed:

- earthquakes
- heat island and heat waves
- floods and droughts

along with the monitoring of well-being and health of people occupying buildings in areas affected by the aforementioned critical events. When the Solutions will be operational, several data will be available. New knowledge can be generated by comparing and reprocessing the data; however, this is only achievable if the data produced by the solutions are interoperable.

In this perspective, the project planned a specific Task for the identifying and validating a reference model for enabling interoperability in the data exchange among the MULTICLIMACT Digital Solutions.

3.2 The reference infrastructure for an interoperable data exchange

The ENEA "Smart City Platform Specification (SCPS) for Interoperability Layer" and its reference implementation ("Smart City Platform" SCP) have been identified as the basis for defining the reference model for interoperability between the MULTICLIMACT digital solutions (details about SCP, SCPS and available tools can be found in [6]).

They enable the communication among heterogeneous platforms or digital solutions that speak different languages, maintaining existing technological implementations and making different data collection and management systems interoperable. The aim is to provide citizens, municipalities and various stakeholders with a valuable tool for collecting and harmonizing useful data from districts, cities and, more in general, urban environment, in order to obtain knowledge on the entire urban management. Furthermore, they are:

- **public**: everybody can adopt them to create its own smart city platform, maintaining the interoperability among the systems;
- **open**: everybody is able to propose new types of UrbanDataset, which is the common format to represent data to be exchanged between SCP and Solutions;

- **replicable**: a digital solution that adheres to the SCPS, in order to connect a platform SCPS-based, can immediately connect to another platform SCPS-based (e.g. a mobility platform connected to the platform of the municipality A, could easily connect to the platform of municipality B).

It is important to highlight that the purpose of the SCPS is not to replace the existing solutions but to allow the harmonization and recovery of data from them at a central horizontal ICT platform, the Smart City Platform (Figure 1). This platform adopts a shared and public approach aimed at enabling interoperability between systems, preventing them from behaving as independent silos.

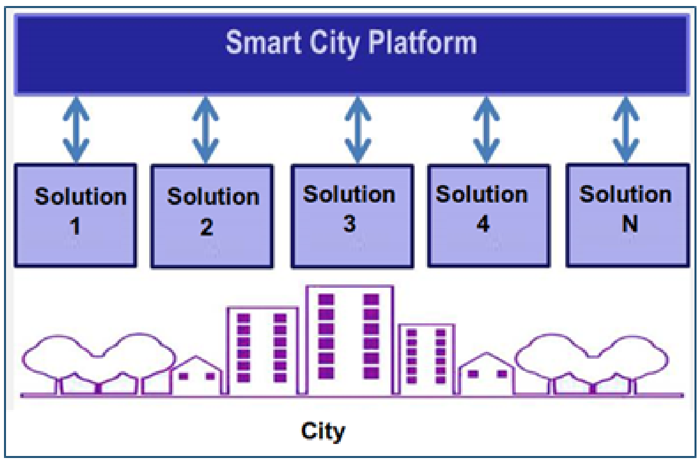

Fig. 1. SCP and Digital Solutions Communication

The SCPS is based on the following key concepts:

- **Smart City Platform (SCP)**: a city management platform that adheres to SCPS specifications. ENEA has developed an SCP prototype for demonstration purposes.
- **UrbanDataset**: the shared format to represent the data to be exchanged between SCP and Solutions, according to the SCPS; it is defined through a univocal and centralized semantic description (the Ontology component), an Abstract Model (providing a syntax-independent description of the common structure of messages) and a syntactic reference implementation (JSON, expressed through a JSON Schema). A message structured according to this format contains a set of significant urban data as well as all the information needed to understand and interpret such data. The data collection is expressed as set of properties, meant as couples key-value.
- **Ontology**: is the component defining the semantic content of the UrbanDatasets, as well as classifying them into categories and sub-categories. Concretely, it provides a shared vocabulary and terms and is expressed using the

OWL Web Ontology Language defined by W3C. Furthermore, it is a prescriptive reference for each UrbanDataset and for its semantic validation; this means that an UrbanDataset must comply with the definition given in the Ontology in order to be considered valid according to the SCPS. The ontology is a dynamic component that can evolve and grow over the time; to cover new application contexts, new terms can be added to the vocabulary and new types of UrbanDataset can be defined in the library, as happened for supporting the MULTICLIMACT scenario.
- **Registry**: internal database of the SCP acting as a register of Users, Solutions, supported UrbanDatasets and Collaborations defined between SCP and the Solutions, both to produce UrbanDatasets and to access UrbanDatasets produced by third parties.
- **UrbanDatasetGateway**: a web service to send the UrbanDataset to the SCP and to get UrbanDataset from the SCP, respecting the production and access permits stored in the Registry database of the SCP.

The Registry and the UrbanDatasetGateway will not be further discussed in this paper as it focuses on complementary aspects to them.

According to the Interoperability Reference Model, the SCPS are split into five independent modules that can be gradually adopted:

- **Functional Specification**: it describes the key concepts of the SCPS, the architecture of the SCP and its components and the functionalities.
- **Collaboration Specification**: it describes the set of information that characterizes the collaboration between a SCP and a Solution.
- **Semantic Specification**: it deals with the semantic definition of data and includes the SCPS Ontology, that ensure a single centralized definition, both of the UrbanDataset and of the properties that compose them, with the same names, formats and units of measurement;
- **Information Specification**: it deals with the syntactic definition of the data, stating the UrbanDataset format and the path to create UrbanDataset messages. The format is defined in terms of Abstract Model and a reference syntax of data exchange: JSON (expressed through JSON Schema).
- **Communication Specification**: it describes the interoperable communication protocol to enable data exchange between a SCP and one or more Vertical Solutions.

3.3 The approach

The reference model for implementing interoperable Smart City Platforms for monitoring natural threats at different geographic scales has been conceived to be:

- applicable at three different geographic scales: building, urban, territorial;
- scalable, in order to ensure that new systems or solutions can connect to the platform without particular efforts and new services can be activated;

– replicable, meaning that the platform can be adopted in any cities or districts similar for features and needs to the ones involved in the project.

It is the result of a process aimed at extending and customizing the "Smart City Platform Specification (SCPS) for Interoperability Layer" and the ENEA "Smart City Platform" for supporting the scenario tackled by the project. Specifically, the following design and validation path has been adopted:

1. **Reference scenario definition**: identification and modelling of some Case Studies that are representative of the MULTICLIMACT digital solutions and types of exchanged information. This step has been structured in three sub-steps:
   (a) Case studies selection:
      i. Identification and description of some cases representative the MULTICLIMACT overall data exchange context;
      ii. Identification of solution's input and output data flow types.
   (b) Case studies analysis and modelling:
      i. Description of the main (not technical) characteristics and functionalities of the involved digital solutions;
      ii. Identification of input and output data flow types coming from different solutions;
      iii. For each type of data flows, definition of an Abstract Data Model providing a detailed description of the exchange data and related requirements, e.g.: mandatory information, use of coded values, units of measure to be used,...
   (c) Abstract Data Models review and generalization:
      i. Checking if it includes types of information and requirements strictly tailored on the Case study; where necessary, update of the Data Model in order to make it as more general as possible;
      ii. Identification of the subset of data that which could be useful to share in an interoperable format (for example KPIs or data useful for calculating KPIs);
      iii. Release of the final generalized Abstract Data Models obtained applying the i) and ii) sub-steps of this sub-step c).

   The main outputs of this step are the "Abstract Data Models" that have been the starting point for designing the UrbanDataset types that define the interoperable format for collecting data for the natural hazards monitoring.
2. **SCPS Semantic and Information analysis and improvement**: checking of the UrbanDataset Specifications against the identified Abstract Data Models coming from Step 1; where necessary, improvement of existing UrbanDatasets or design, development and publication of new ones. This step has produced the key component of the interoperability reference scenario: the UrbanDataset Specifications that are deeply described in Section 4.2.
3. **Interoperability reference model validation**: demonstration of the interoperability among the MULTICLIMACT digital solutions involves providing one of the four demo sites in the MULTICLIMACT Project, specifically

the Municipality of Camerino, with an SCP instance and enabling interoperable communication among the solutions. It was organized in the following sub-steps:
(a) Setup of ENEA SCP and dashboard for Camerino Municipality (that is part of one of the four demo sites of the project)
(b) UrbanDatasets implementation in the Digital Solutions
(c) Configuration of the collaboration between digital solutions and SCP
(d) Communication implementation and data exchange activation
(e) Preliminary test and validation

This paper is focused on the results obtained performing the first and second steps of the path; the last one (interoperability reference model validation) will be no further treated because it is still not be implemented.

4 The preliminary reference model for interoperability

4.1 The reference scenario

The reference scenario is the basis for extending and customizing the "Smart City Platform Specification (SCPS) for Interoperability Layer" and enabling the interoperability in the data exchange among the digital solutions developed and targeted for MULTICLIMACT project's purposes. It is composed of some Case Studies that are representative of the MULTICLIMACT digital solutions and types of exchanged information. It does not have the ambition to depict all cases implemented in the context of the project nor all the natural hazards monitoring scenarios; rather it aims to:

- identify a set of fundamental requirements and characteristics capable of representing a subset of them;
- outline the approach to adopt for expanding the MULTICLIMACT Interoperability Reference Model in order to connect further digital solutions or replicate it in other contexts.

The Case Studies identified and analyzed for depicting the reference scenario are summarized in Table 1. Due to limited space, only one of them is explored in depth.

Earthquake monitoring and damage estimation case study This case study concerns the monitoring of seismic events and their impact on environment, cities, buildings and people. Data are collected or elaborated by digital solutions and shared on a Smart City Platform. It includes three types of digital solutions and two sub-case studies:

- **Earthquake detection and damages estimation**: it involves two digital solutions; a Digital Solution A, capable of collecting data on an earthquake, and a Digital Solution B, able to estimate physical damages to buildings and curves of resilience (operational and socio-economical) of points of interest

Table 1. Natural threats monitoring case studies

Name	**Description**	**Applicability scale**	**Abstract Data Models**
Earthquake monitoring and damage estimation	Monitoring of seismic events and their impact on environment, cities, buildings, and people	– Building – Urban – Territorial	– Earthquake events – Resilience indicators – Earthquake damaged buildings counter – Building structural simulation
Prediction of environmental behavior in case of heatwaves	Prediction of the critical parameters (like temperature) of outdoor urban space in case of heat waves, but also the analysis of building's energy efficiency	– Building – Urban	– Urban surface conditions prediction – Building energy consumption and demand
Flood monitoring	Monitoring of parameters useful for Decision Support Systems to warn against macrostability failure in dikes and deformation and leakage in movable barriers under flood and drought conditions	– Urban – Territorial	– Hydrological extremes time series
Comfort and well-being indoor monitoring	Monitoring of parameters concerning comfort and healthcare of people inside buildings	– Building	– Health monitoring – Microclimate monitoring

and critical infrastructures based on the occurrence of seismic events. When an earthquake occurs, the Digital Solution A sends the related information to the Smart City Platform where they remain available for all accredited solutions and users. Once a day the Digital Solution B send a request to SCP for receiving the last "Earthquake events" message; then, it checks if the message is different from the one received the day before and, in case, it calculates the level of damage of the buildings in the affected area and the resilience indicators. Finally, the digital solution B send this information to SCP where they remain available for all accredited solutions and users. The sequence of the exchanged messages is shown in Figure 2.

– **Building structural behaviour simulation**: it involves one digital solutions and refers to the simulation of structural behaviour of buildings under extreme natural hazard conditions (earthquake, wind and fire). Specifically, this Digital Solution can calculate structural behaviour using an architec-

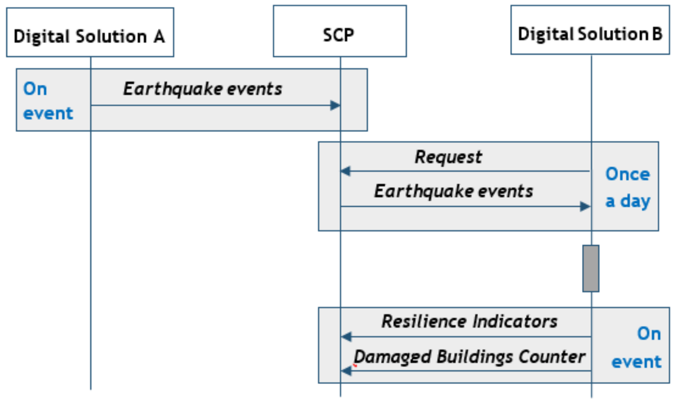

Fig. 2. "Earthquake detection and damages estimation" case study sequence diagram

tural BIM model of a building and is capable of comparing simulated data with the structural design codes of a specific country (National codes and Eurocode); it also allows to obtain compliance documents for the simulated structure. The Digital Solution is meant for the study of the existing building stock and it's response to extreme natural hazard conditions with the aim of preventing future disasters. To study existing building stock can be beneficial to apply security and correction measures in a specific building or area. The inputs used by the Digital Solution to execute elaborations are not acquired through the Smart City Platform which simply receives the obtained information from the Digital Solution and makes they available for all accredited solutions and users.

The Abstract Data Models coming from this Case study are:

- **Earthquake events**: it represents data concerning one or more seismic event (real or simulated).
- **Resilience Indicators**: it represents aggregated indicators of socio-economic impact due to natural hazards.
- **Earthquake Damaged Building Counter**: it represents data on the number of buildings damaged in the specified geographic area due to a seismic event.
- **Building Structural Simulation**: it represents data related to the simulated structural behavior of buildings for earthquake conditions.

An example of connection between vertical Solution and SCP based on this Case Study, as described also in Figure 3 , is the following:

- the "Seismic Event Monitoring" Solution implements a simple software module that
  - exports the dataset in the JSON format of the "Earthquake Events" UrbanDataset;

  - pushes the UrbanDataset towards the SCP (as a client, in respecting of the "UrbanDatasetGateway" web service interface);
- the SCP is configured to receive the "Earthquake Events" UrbanDataset from the "Seismic Event Monitoring" Solution, so the "UrbanDatasetGateway" web service is ready, waiting for UrbanDatasets from the solution;
- the connection between Solution and SCP can be enabled and automated, with the sending of the UrbanDataset, from Solution to SCP, with the configured frequency.

The other vertical solution in Figure 3, "Impact and Resillence Assessment", works in the same way, exporting and pushing (or requesting and importing) the expected UrbanDatasets.

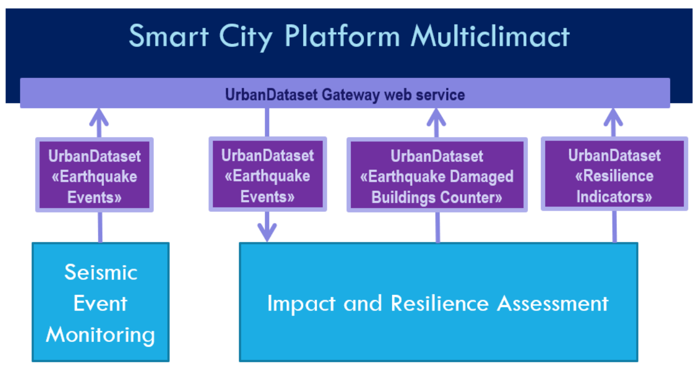

Fig. 3. Example of Reference Model implementation

"Prediction of environmental behavior in case of heatwaves" case study. This case study concerns the prediction of the critical parameters (like temperature) of outdoor urban space in case of heat waves, but also the analysis of building's energy efficiency. Data are collected or elaborated by digital solutions and shared on the Smart City Platform. It includes two types of digital solutions and two sub-case studies:

- **Prediction of heat mitigation KPIs**: it involves one digital solutions that, using the weather forecast as an input (currently not acquired through the Smart City Platform), can predict the surface temperature of a pavement and deduces the apparent, radiant and operative temperatures from it. The solution runs once a day predicting these KPIs for the following 24h; these values are then sent to the Smart City Platform where they remain available for all accredited solutions and users.
- **Building energy simulation** it involves one digital solutions and refers to the prediction of building behavior (consumption and demand) under extreme weather conditions as well as the simulation of building behavior when

applying correction measures such as heat mitigation pavement solution. The Digital Solution consists of a physics base simulation model with EnergyPlus simulation engine; specifically, it can simulate energy consumption and demand using an architectural BIM model of a building. It is meant for the study of the existing building stock and it's response to extreme natural hazard conditions with the aim of preventing future disasters. The inputs used by the Digital Solution to execute elaborations are not acquired through the Smart City Platform which simply receives the obtained information from the Digital Solution and makes they available for all accredited solutions and users.

In this Case Study two Abstract Data Models have been designed:

- **Urban Surface Conditions Prediction**: it represents some KPIs concerning the predicted conditions of an urban surface (for example pavement) in a determined time horizon.
- **Building energy consumption and demand**: it defines some KPIs representing the building behavior, in terms of energy demand and consumption, under extreme weather conditions.

"Flood monitoring" case study. This case study involves an early warning system that leverages surrogate models and fiber optics measurements as input to quantify the state (and early signs of failure) of two types of flood defenses: dikes and box movable barriers. The system for both scenarios operationally calculate a set of Key Performance Indicators (KPIs), consisting of time series data, which are exported to the Smart City Platform on a daily or sub-daily frequency where they remain available for all accredited solutions and users.

This Case Study has identified one Abstract Data Model, "**Hydrological extremes time series**" for representing time series relating to several types of parameters (macro stability safety factor, leakage safety factor,...) for the prevention, defence and management of floods and droughts scenarios.

"Comfort and well-being indoor monitoring" case study. This case study deals with the monitoring of some parameters of indoor environments (such as air quality, temperature, humidity, and physiological responses of occupants, among others) that can be useful to make evaluation for improving both comfort and energy efficiency of buildings. It involves a digital solution that not only enhance the monitoring and management of indoor environments (which are exported to the Smart City Platform where they remain available for all accredited solutions and users) but also provide actionable insights that can be used to improve both occupant well-being and energy efficiency.

In this Case Study two Abstract Data Models have been designed:

- **Microclimate Monitoring**: it represents several parameters useful for depicting the conditions of indoor environment both from the quality and energy efficiency perspectives.

– **Health Monitoring**: it defines the set of parameters able to represent the physical health condition of the occupants of an indoor environment.

4.2 The SCPS UrbanDataset for the MULTICLIMACT reference scenario

Starting from the Abstract Data Models identified through the reference scenario designing, the "Smart City Platform Specification (SCPS) for Interoperability Layer" has been customized and extended for supporting the monitoring of natural threads, well-being and health parameters of people occupying building in the affected areas. The results have been the design and implementation in the SCPS ontology of some new UrbanDataset types, the update of an existing one, the setting-up of their JSON implementations. Specifically:

– **"Microclimate Monitoring" UrbanDataset**, that can be used to provide comfort parameters relating to inhabited environments, has been updated to include more parameters, consistently with the Abstract Data Model defined in the "Indoor comfort and well-being" case study. This action demonstrates the flexibility and scalability of the reference infrastructure adopted and its ability to respond to new needs.

Then, the following new UrbanDatasets have been designed:

– **"Earthquake Events" UrbanDataset**: it provides data concerning one or more seismic events (timestamp of the event detection, epicenter, magnitude, depth), specifying whether the data relates to a real or simulated event. So, it can be used to share information that actually happened, as well as useful information for carrying out simulations.
– **"Resilience Indicators" UrbanDataset**: it gives aggregated indicators of socio-economic impact due to natural hazards, indicating the resilience evolution over time and set of the affected nodes (Points of Interest and Critical Infrastructure). The UrbanDataset is not constrained to a specific indicator calculation method neither to a specific natural hazard, and it has been designed in order to support the aggregation of the indicators at two different geographic scales: urban scale (district or town) and territorial scale (province, region or country). This UrbanDataset also allows to indicate whether the data relates to a real or simulated event.
– **"Earthquake Damaged Buildings Counter" UrbanDataset**: it deals with data on the number of buildings damaged in the specified geographic area due to a seismic event. The level of damage has to be indicated according to the European Macroseismic Scale 1998 (EMS-98) and can refer to two different geographic scales: urban scale (district or town) and territorial scale (province, region or country). This UrbanDataset also allows to indicate whether the data relates to a real or simulated event.
– **"Hydrological Extremes Time Series" UrbanDataset**: it allows to provide different types of parameters, collected as time series, useful to prevent, defend and manage floods and droughts scenarios; for example, indicators to

evaluate the status of defence systems like movable barriers or dikes. Each measurement can be georeferenced by indicating the geographic coordinates of the detection point and the quality and reliability of the data can be specified. The UrbanDataset has been designed so that the set of supported parameters can be easily expanded over time.

- **“Urban Surface Condition Prediction” UrbanDataset**: it allows to provide up to four different KPIs (surface, apparent, radiant and operative temperatures) indicating the prediction of urban surface conditions in a determined time horizon. The UrbanDataset has been designed in order to be able to be used for different kinds of surface (e.g. footpath, roads, wall,...) and materials they are composed of (e.g. pavement, asphalt,...). The set of supported surfaces and materials can be easily expanded over time. The predictions can be georeferenced by indicating the geographic coordinates where the surface is located.
- **“Health Monitoring” UrbanDataset**: it provides various parameters regarding a person’s health status (e.g. blood oxygen saturation level, hear rate, heart rate variability,...). For privacy reasons, the UrbanDataset allows to identify the device/sensor that collects the data, but does not allow to identify or georeference the person.

The UrbanDatasets concerning the "Building energy simulation" and "Building energy consumption and demand" have not been yet implemented in the SCPS Ontology.

As an example, Figure 4 shows an human-friendly representation of the semantic definition of the of "Earthquake Damaged Buildings Counter" UrbanDataset, that has been included in the SCP Ontology, and Figure 5 provides a fragment of a JSON implementation example regarding data aggregated at city level. Note that the Region which data is refer to is expressed as code ("RegionCode" property). This code belongs to the NUTS classification (Nomenclature of territorial units for statistics) that has been adopted by the SCPS Ontology for identifying European regions.

4.3 The three management scales of the built environment

As aforementioned, the new UrbanDatasets designed for monitoring of natural threats have been added to the SCPS UrbanDataset library. Since the “Smart City Platform Specification for Interoperability Layer” is conceived to support the development of platforms capable of collecting data from applications operating in the different contexts of the Smart city, the SCPS Ontology structures the library according to categories and subcategories suitable for representing the types of smart city applications and does not provide clear reference to the built environment scales, although the category “Built environment” is present. Nevertheless, a more comprehensive match between the two perspectives can be made, as shown in Table 2 (in the "Built environment scale" column, the "X" symbol means that UrbanDatasets are not yet available in the related subcategory; the “New UrbanDataset” column shows the UrbanDatasets relating only to the monitoring of natural threats).

UrbanDataset Identification				
Scope	Provides data on the number of buildings damaged in the specified geographic area due to a seismic event. The level of damage is indicated according to the European Macroseismic Scale 1998 (EMS-98)			
Category / Subcategory	PublicSafetyPolicyEmergencyResponse / NaturalHazard			
Identifier	EarthquakeDamagedBuildingsCounter-2.0			
Name	Earthquake Damaged Buildings Counter			
URI	https://smartcityplatform.enea.it/specification/semantic/2.0/ontology/scps-ontology-2.0.owl#EarthquakeDamagedBuildingsCounter			
UrbanDataset Properties ** properties marked with an asterisk require to indicate, at instance level, the adopted calculation method (e.g. "average", "total", "instantaneous",...)*				
Name	**Description**	**Mandatory**	**Format/Code list**	**Unit of Measure**
ModerateDamageBuildingCount	Number of buildings that suffered D2 damage level ('moderate' according with EMS-98)	yes	integer	Not applicable
NegligibleDamageBuildingCount	Number of buildings that suffered D1 damage level ('negligible' according with EMS-98)	yes	integer	Not applicable
SubstantialDamageBuildingCount	Number of buildings that suffered D3 damage level ('substantial to heavy' according with EMS-98)	yes	integer	Not applicable
TotalDestructionBuildingCount	Number of buildings that suffered D5 damage level ('total destruction' according with EMS-98)	yes	integer	Not applicable
VeryHeavyDamageBuildingCount	Number of buildings that suffered D4 damage level ('very heavy damage' according with EMS-98)	yes	integer	Not applicable
coordinates	Geographical reference of the damaged area	yes	Aggregated property	Not applicable
subProperty: *format*	Wgs84 format in which the coordinates are expressed (optional attribute)	no	string FormatCode.gc	Not applicable
subProperty: *height*	Altitude (optional property)	no	double	Not applicable
subProperty: *latitude*	Latitude	yes	double	Not applicable
subProperty: *longitude*	Longitude	yes	double	Not applicable
timestamp	The date and time in wich the damages were detected	yes	dateTime	Not applicable
CountryCode	A code identifying the country	no	string CountryCode.gc	Not applicable
EventID	An unique identifier for the event	no	string	Not applicable
ProvinceName	Province name	no	string	Not applicable
RegionCode	A code identifying a region	no	string RegionCode.gc	Not applicable
SchemeID	Identifies an encoding scheme	no	string	Not applicable
SimulatedFlag	Indicates if the reported event is real (false) or simulated (true)	no	boolean	Not applicable
TownName	Extended town name (e.g. Roma, Anguillara Sabazia, ecc.)	no	string	Not applicable
ZIPCode	Zip Code	no	string	Not applicable
ZeroDamageBuildingCount	Number of buildings that did not suffer damages	no	integer	Not applicable

Fig. 4. Semantic definition of the "Earthquake damaged Buildings Counter" UrbanDataset

```
"UrbanDataset": {
  "specification": {
    "version": "2.0",
    "id": {
      "value": "EarthquakeDamagedBuildingsCounter-2.0",
      "schemeID": "SCPS"
    },
    "name": "Earthquake Damaged Buildings Counter",
    "uri": "https://smartcityplatform.enea.it/specification/semantic/2.0/ontology/scps-ontology-2.0.owl#EarthquakeDamagedBuildingsCounter",
  .......
  "values": {
    "line": [
      {
        "id": 1,
        "timestamp": "2024-04-24T09:30:00",
        "coordinates": {
          "format": "WGS84-DD",
          "latitude": 43.13,
          "longitude": 13.06},
        "property": [
          {
            "name": "EventID",
            "val": "SIM-001"},
          {
            "name": "SchemeID",
            "val": "MSE"},
          {
            "name": "ZeroDamageBuildingCount",
            "val": "1200"},
          {
            "name": "NegligibleDamageBuildingCount",
            "val": "60"},
          {
            "name": "ModerateDamageBuildingCount",
            "val": "15"},
          {
            "name": "SubstantialDamageBuildingCount",
            "val": "5"},
          {
            "name": "VeryHeavyDamageBuildingCount",
            "val": "3"},
          {
            "name": "TotalDestructionBuildingCount",
            "val": "2"},
          {
            "name": "TownName",
            "val": "Camerino"},
          {
            "name": "ProvinceName",
            "val": "Macerata"},
          {
            "name": "RegionCode",
            "val": "ITI3"},
          {
            "name": "SimulatedFlag",
            "val": "true"}
        ]},
```


Fig. 5. Sample fragment of the "Earthquake damaged Buildings Counter" UrbanDataset

Table 2. Match between SCPS Ontology's categories and subcategories and built environment scales

Categories	**Sub-categories**	**Built environment scale**	**New Urban-Datasets**
Built environment	Smart Home	Building	Microclimate Monitoring
	Smart Building	Building	
	Land use and management	Urban area/Territory	Urban Surface Prediction Conditions
Water and wastewater	Water collection and management	Urban area/Territory	
	Water distribution	X	
	Water consumption	X	
	Wastewater management	X	
Waste	Citizens engagement	X	
	Collection and segregation	X	
	Waste disposal	X	
Energy	Energy supply	Building/Urban area	
	Energy transmission and distribution	Building/Urban area	
	Energy demand	Building/Urban area	
Transportation	Travel demand/consumption	X	
	Traffic management	Urban area	
	Surveillance	Urban area	
Education	Learning outcomes	X	
	Learning and teaching	X	
	Service management	X	
Health	Health care systems	Building	Heal Monitoring
	Health care delivery	X	
	Communication	X	
Socio-economic development	E-Governance	Urban area	
	Social Innovation and Inclusion	Urban area	
	Economy and Business	X	
Public safety, policy and Emergency Response	City surveillance and crime prevention	X	Earthquake events, Resilience Indicators, Earthquake Damage Building Counter, Hydrological extremes time series
	Communication	Urban area/Territory	
	Natural Hazard	Building/Urban area/Territory	

5 Conclusions and next steps

In this paper, with the goal of monitoring natural threats at different geographic scales, we presented a preliminary reference model, defined through public specifications for the interoperability, preparing a demonstration that use a smart city platform, based on the above-mentioned specification. The specification for the interoperability is named "Smart City Platform Specification (SCPS) for Interoperability Layer" and the platform SCPS-based is named "Smart City Platform" (SCP). This work is the result of a process aimed to extend and customize the SCPS starting from a reference scenario depicted in the context of the MULTICLIMACT project and then demonstrate the interoperability with the reference model through the SCP platform. Currently, the design of the reference model has been almost finalized and the following outcomes are available: the semantic and syntax definition of the interoperability format (SCPS UrbanDataset) to exchange data for the most part of the data flows (Abstract Data Models) identified in the reference scenario, and the UrbanDataset speficifications for the missing ones will be available in the next future. The design process has demonstrated the scalability of the SCPS, adopted as reference architecture, and its applicability to the three geographic scales. The next steps involve validating the reference model and demonstrating its replicability by implementing it in a different geographic context. Validation will be conducted by demonstrating the interoperability among the MULTICLIMACT digital solutions, as previously explained, using the Italian demo site in the MULTICLIMACT project, specifically the Municipality of Camerino, as a testing ground. This site will feature an SCP instance (named SCP-Multiclimact) that will enable interoperable communication among the solutions.

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