D10.4 HYPERION Roadmap and Project Handbook

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[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[2] **PU**=Public, **CO**=Confidential, only for members of the consortium (including the Commission Services), **CI**=Classified, as referred to in Commission Decision 2001/844/EC

Modifications Index

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ACRONYMS AND ABBREVIATIONS

EU	European Union
WP	Work Package
GDPR	General Data Protection Regulation
EC	European Commission
NGO	Non-governmental organization
CC	Climate Change
HRAP	Holistic Resilience Assessment Tool
CH	Cultural Heritage
BCS	Business Continuity Strategy
FPA	Funding Prioritization Analysis
IOT	Input-Output Table
VDT	Vendor Dependence Table
HT	Hygro-Thermal
SG	Structural and Geotechnical
SES	Stochastic Event Set
SSA	Sector Shutdown Analysis
DSS	Decision Support System
OMS	Operational Mesoscale System

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Executive Summary

HYPERION is a H2020 framework project funded under grant agreement 821054 which aims to introduce a research framework for assessing the risk and resilience of Cultural Heritage sites subject to natural hazards in a climate-change era.

1. Introduction

1.1 Objectives of the Deliverable

The purpose of this deliverable is to provide a handbook of the project's perspective, methods and outcomes, as well as a long-term roadmap for wider communities' and other stakeholders' engagement in the following 5-year period, suitable for promotion in the context of the European policy.

1.2 Structure of the Deliverable

The document is organized in two main parts. In the first part, we present the project perspective, in an effort to address stakeholders, and provide them with technical information on the project outcomes, proper strategies for responding to climate change and other hazard scenarios, practical insights on available decisions and financial tools to mitigate risks, and guidelines for understanding the socioeconomic impacts of decision making. In other words, the first part aims to equip stakeholders with all the required information and tools to cope with the effects of climate change on their cities, including historic areas. For this purpose, it is organized in the following sections.

- technical information on sustainable reconstruction of historic areas,
- proper adaptive response strategies for CC and other hazards scenarios,
- post-disaster reconstruction example,
- practical checklists and references to assist practitioners, field-workers, cities and cultural authorities, etc. in better decision making,
- recovery requirements for various sectors,
- information on financial tools to mitigate risk, including a novel set of CH-area-specific parametric insurance plans, designed to cover expected degrees of extreme CC and non-CC event severity
- guidelines and techniques to encourage, facilitate, and develop bespoke reciprocal agreements between same type of businesses for timely service recovery.

In the second part of the document, we provide a roadmap for wider communities' and other stakeholders' engagement in the following 5-year period, including several strategies to foster the adoption of the key project innovations within the wider European community of Cultural Heritage sites operators, city managers, and other relevant interested parties.

2. HYPERION Project Handbook

Environmental threats—both natural and human-made—have long threatened cultural sites. Monuments and sites that have stood on the Earth for centuries, have always suffered from exposure to wind and rain; extreme weather events; intense geological phenomena such us earthquakes, volcano explosions; the ravages of time; destruction as a result of collateral or intentional damage in wartimes. Especially in the last century, new factors such as pollution, Climate Change (CC) and other human-made factors have taken their toll.

In conservation and restoration, considering aspects such as building technologies, materials, structural issues, preventive measures and restoration strategies, resilience and adaptation methodologies is a particularly challenging and time-consuming process. Moreover, the impact of various climatic and other parameters on Cultural Heritage sites is hard to understand and difficult to assess quantitatively and qualitatively.

The HYPERION EU project, financed by European Union's Horizon 2020 research and innovation programme, aims to provide the appropriate tools in order to better understand the effects of climate change, ravages of time, intense geological phenomena and extreme weather conditions on archaeological sites and cultural heritage monuments.

Thus, HYPERION enables end users to have a better understanding of the dangers and threats to tangible cultural heritage, make decisions for a swifter and more effective response, and contribute to the sustainable reorganisation of the historical regions under threat. HYPERION adds on existing tools, by utilizing sensors, including fixed instruments within carefully selected spots in the historic areas, drones, wide-area satellite services and even community engagement tools, to arrive at a more comprehensive and synoptic monitoring and emergency response/damage mapping system. In other words, HYPERION acts as an innovative planning tool that will maximize the performance and the rapidity of the decision-making process for addressing multi-hazard risk understanding, better preparedness, faster, adapted and efficient response, and sustainable reconstruction of historic areas.

HYPERION therefore perfectly serves policy makers, cultural institutions, municipalities, public authorities, responsible for the management and preservation of national and local tangible assets as well as researchers, archaeologists, conservators and other professionals with a key role in safeguarding cultural heritage. HYPERION provides stakeholders with unique benefits that surpass the usual capabilities of decision support systems. It can perform scenario, short-term, and long-term damage assessments, therefore providing a tool that enables end user training in extreme and unprecedented scenarios, equipping them with the necessary experience to better cope with the unforeseen.

And by using its integrated mobile application for Heritage Awareness and Participation, HYPERION engages local communities and the citizens, mobilising them to identify potential hazards and raise awareness of issues relating to the preservation of regional cultural heritage.

HYPERION has performed extensive tests in four flagship sites, in the Medieval city of Rhodes, Greece, in the Albayzín and El Realejo of Granada, Spain, in Tønsberg, Norway and in Venice, Italy. Though these test, HYPERION has shown its ability to bridge the gap between urban development, resilience planning and heritage management in order to boost collaboration among all involved stakeholders and make our cities more climate neutral and resilient. Its vision is to stimulate and promote development and support a wide **adoption of solutions for climate change mitigation and adaptation in historic urban districts.**

2.1 Technical information on sustainable reconstruction of historic areas

The HYPERION approach supports the Horizon 2020 'Heritage Alive' orientation to "[increase] resilience and sustainable reconstruction of historic areas to cope with climate change and hazard events"[3]. The goal is the **development and uptake of advanced methodologies for resilient urban planning for historic and modern urban districts, supporting their adaptation to climate change.** In doing so, HYPERION aims to provide support to European authorities and decision makers for accommodating common evidence-based policies, strategies, and procedures, by introducing

- **advanced technologies for assessing impacts** of climate change and weather conditions on urban districts (historic and modern, including effects on the structural, environmental, economic, and socio-cultural dimensions of these socio-ecological systems), and
- advanced methods and technologies for **climate neutral and resilient urban planning** that take the enabling factors of culture and heritage into account.

Therefore, HYPERION renders historic areas more socially, economically & environmentally resilient, while proactively enhancing our knowledge to better cope with future disasters. The overall methodology followed is shown in Figure 1, and explained in the following paragraphs. In summary, HYPERION is capable of downscaling the created climate and atmospheric composition as well as associated risk maps down to the 1x1 km scale, identifying specific damage functions for Cultural Heritage (CH) materials, and applying atmospheric modelling for specific Climate Change (CC) scenarios at this refined spatial and time resolution. This allows for an accurate quantitative and qualitative impact assessment of the estimated micro-climatic and atmospheric stressors. HYPERION performs combined hygrothermal and structural/geotechnical analysis of the CH sites (indoor climate, HVAC, related strains and stresses, etc.) and damage assessment under normal and changed conditions, based on a wide range of climatic, structural and historic data. The latter are coming from an integrated monitoring system and are coupled with simulated data (under our holistic resilience assessment platform-HRAP). They are analysed through a data management system, and are fed into a decision support system (DSS) so as to provide

[3] https://ec.europa.eu/research/environment/index.cfm?pg=cultural

proper adaptation and mitigation strategies, and support sustainable reconstruction plans for the CH damages.

The resulting map is in essence a digital twin of the entire city, including historic areas (Figure 2), which will be used by the local authorities to assess the threats of CC (and other natural hazards), in order to visualize the built heritage and cultural landscape under future climate scenarios, model the effects of different adaptation strategies, and ultimately prioritize any rehabilitation actions to best allocate funds in both pre- and post-event environments.

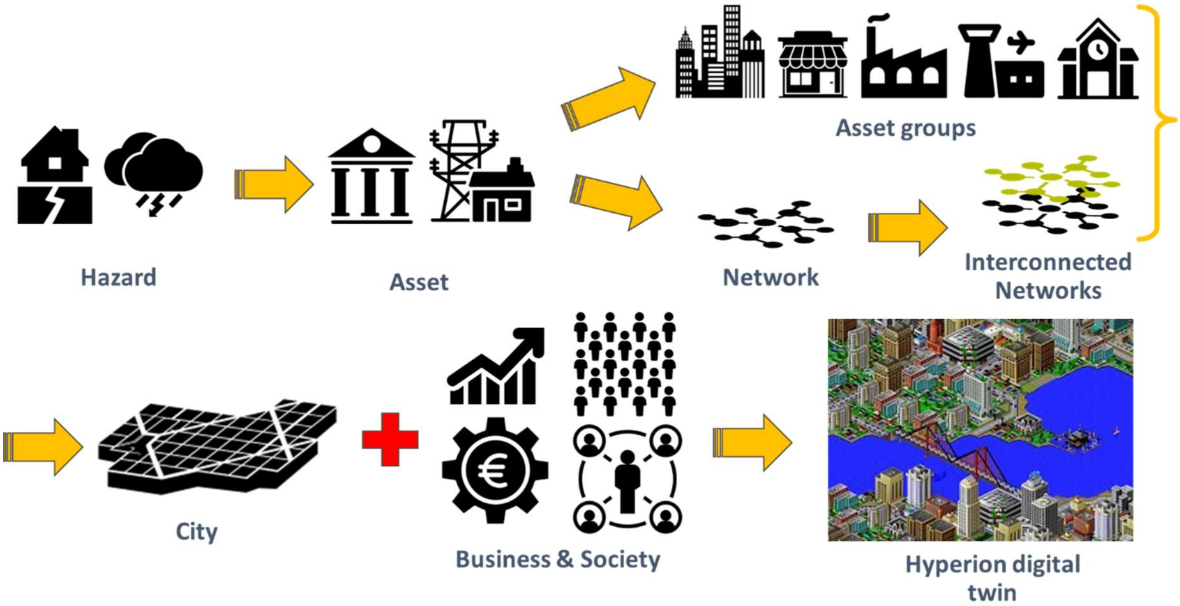


Figure 1: The HYPERION approach

Figure 2: The HYPERION digital twin

Technical information of the aforementioned architecture and digital twin structure, is included in the following paragraphs.

1. Reliable quantification of climatic, hydrological and atmospheric stressors

HYPERION employs quality assessed numerical modelling results for selected CC scenarios, covering processes and interactions from the short-term to the long-term (10-80 years). These data are processed in order to estimate quantitative indicators for the potential impacts of CC on historic areas from the individual building to a regional level, including also aspects related to their aesthetics due to long-term exposure of the structures on air pollution and microclimatic conditions. Changes of both the average climate and the increase of the intensity and the frequency of extreme climatic/weather events are considered in this modelling approach. A Land Surface model is also used, in order to account for the impact of climate and atmospheric composition on soil surface parameters (e.g., the presence of liquid water), thereby quantifying the structural and thermo-physical impacts on the structural elements and operation. The high-resolution modelling effort exploits existing sources of climate and air pollution data, enriched with in situ sensor data (see for example Figure 3), and enhances their added value through risk indicators for selected risk “hot-spots” (e.g., foundations, facades of buildings), introducing a risk modelling interface with the HYPERION resilience assessment platform.

In summary, the system provides the following:

- ❑ Very-high spatial and temporal resolution numerical modelling results together with an optimized allocation of temporal study periods
- ❑ Generates and applies a dynamic down - scaling system consisting of an Operational Mesoscale System (OMS) and a reference database of meteorological forecast methodology based on precomputed computational fluid dynamics (CFD) results
- ❑ Utilizes a multi-nesting methodology in order to obtain high resolution (of the order of several hundred meters) at the areas of interest (see for example Figure 4)
- ❑ Employs local measurements by deployed weather stations to update and recalibrate predictions, providing improved predictions as more data is gathered.

The system performing the dynamical downscaling of gust forecast and localization of other meteorological variables is designed to operate as an embedded part of the HYPERION HRAP system, allowing us to provide long-term CC estimates (e.g Figure 5) of downscaled weather statistics with high resolution covering each site.

Figure 3: A HYPERION smart sensor tag place on the Torre dell’ Orologio in Venice

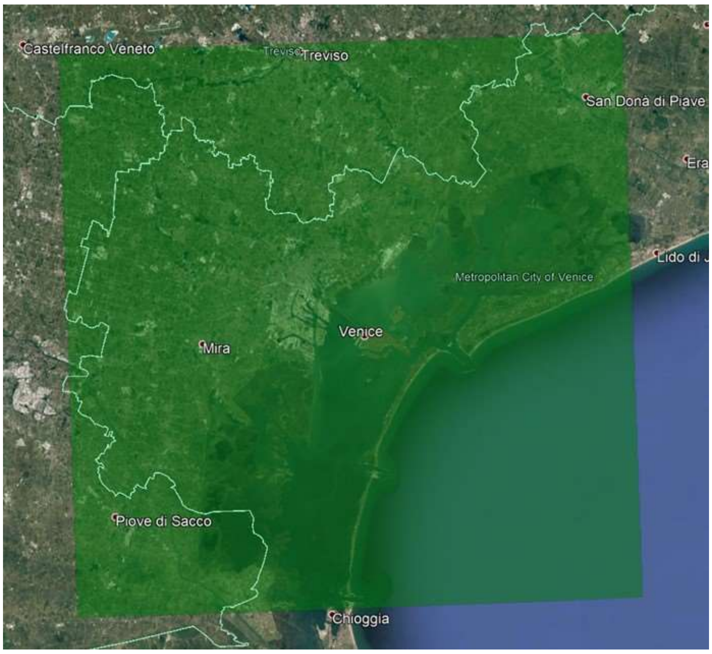


Figure 4: Domain extents and the topography layer for the of the model domain for the pilot domain of Venezia.

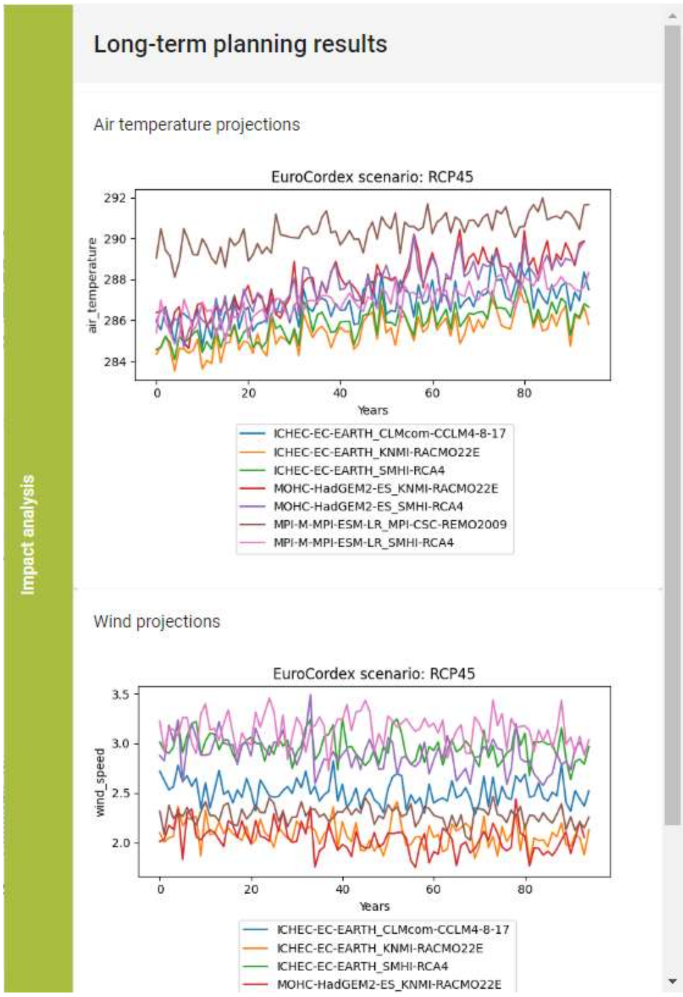


Figure 5: Long-term planning – EuroCordex projections (air-temperature and wind speed)

2. Multi-Hazard modelling

Multi-Hazard modelling covers single, cotemporaneous (e.g., extreme temperature, humidity, wind, air pollutants) and cascading (mudflow/landslide after rain, etc.) hazards. Inundation maps are provided for specific catchments by using hydrological modelling for various precipitation capacities, while seismic hazard is quantified in terms of seismic intensity levels (peak ground acceleration, spectral estimates, and surface faulting deformations) and their spatial/temporal distribution for the historic area, by using stochastic modelling approaches (probabilistic seismic hazard analysis). Examples of the aforementioned information that could be accessed by stakeholders when using the HYPERION platform are given in Figure 6 (for extreme weather conditions) and in Figure 7 (for seismic hazard) modelling.

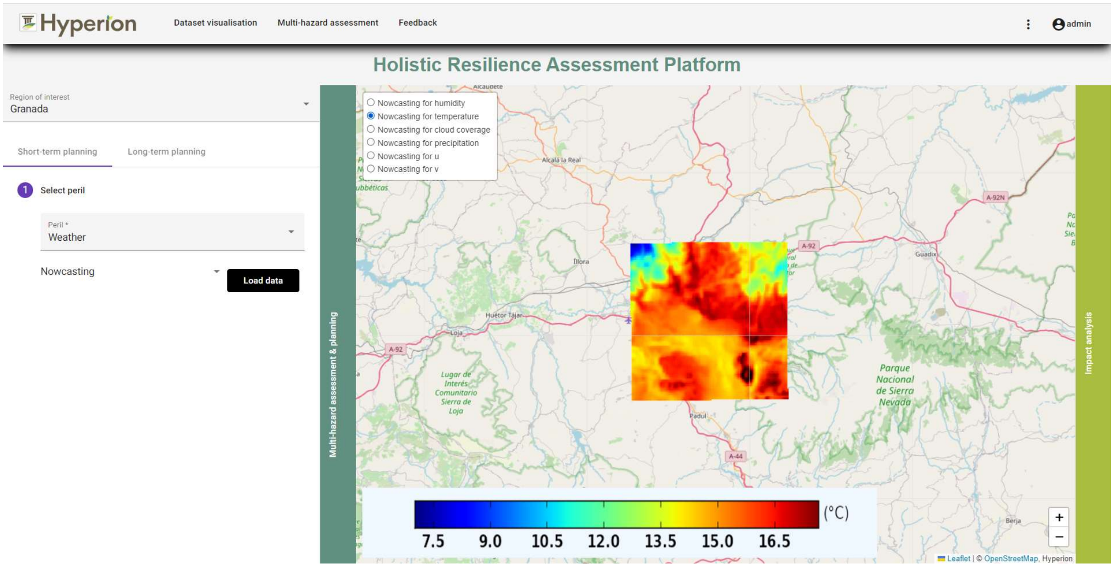


Figure 6: Short-term planning options (Weather hazard)

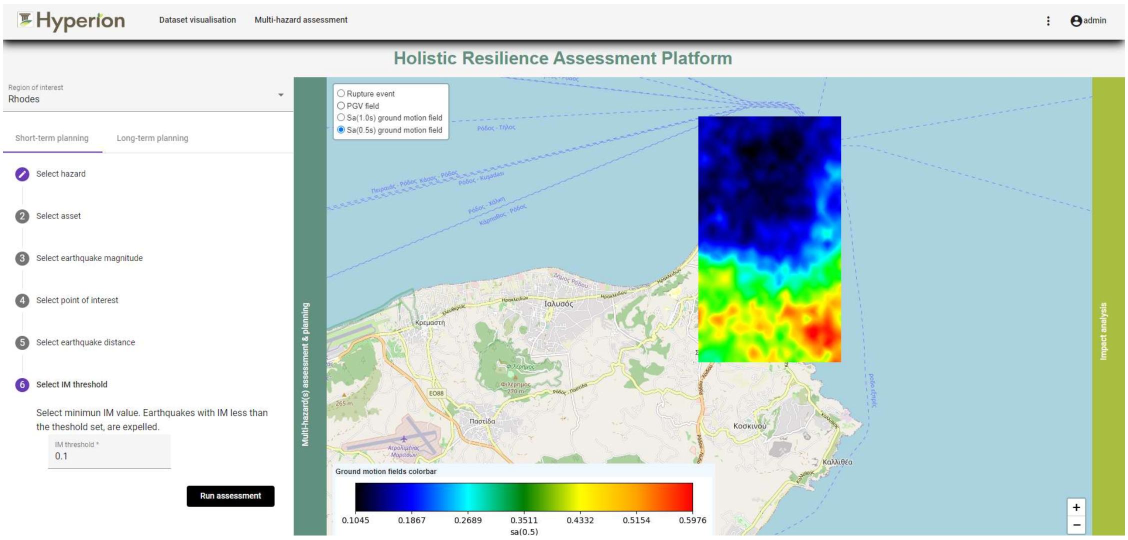


Figure 7: Short-term planning options (Seismic hazard)

3. Environmental and material monitoring including state identification and damage diagnosis

Asset

A multitude of state-of-the-art technologies and algorithms have been utilized together with sensors such as visible spectrum cameras, hyper-/multi-spectral cameras, thermal/infrared/Ultra-Violet sensors, mounted on vehicles and drones to get a precise inspection of CH sites. As a result, HYPERION is capable of providing a detailed representation of buildings of interest (as for example shown in Figure 8) and a comprehensive system to monitor CH in historic areas to ensure regular and efficient maintenance and early detection of damage, degradation and emerging hazards, as well as rapid post-hazard event damage inspection and performance of the CH buildings and sites. For this reason, the Remote Sensing-based multiscale monitoring system (RS-MMS), which integrates data and outputs from various remote sensing platforms and sensors (Figure 9) was designed and developed in order to match the monitoring needs for individual CH elements and hazard scenarios in a synoptic manner. RS-MMS includes innovative approaches that satisfy the diverse information requirements, while making use of state of the art and emerging techniques.

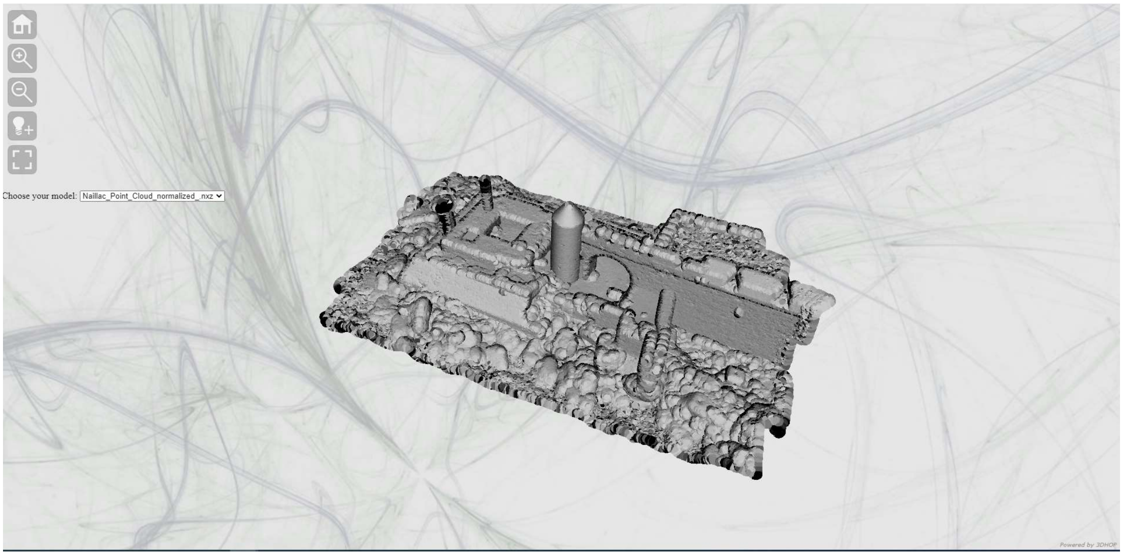


Figure 8: Tier 1 building's model visualisation

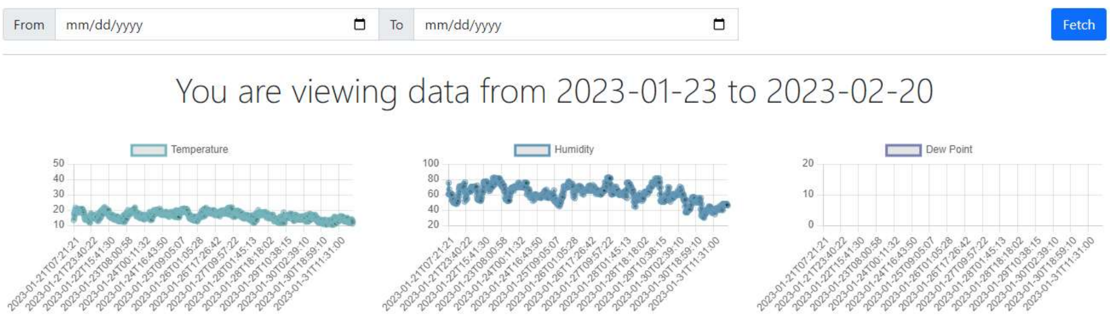
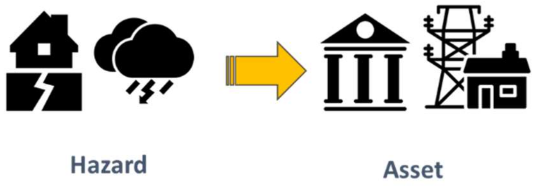


Figure 9: Tier 1 Sensor's historic data

4. Analysis of building materials and deterioration processes



HYPERION can classify the various building materials used in the construction of the different buildings, identify and characterise the main building materials adopted in cultural assets of interest, identify and map their deterioration patterns (e.g. Figure 10), and produce a set of technical data for all the different materials to be integrated in the HT simulator tool and the HRAP platform. These included the petrographic and physical-mechanical characterisation of fresh, unaltered samples. Vulnerability assessment requires knowledge on the decline of physical-mechanical properties of building materials with deterioration. For this reason, accelerated aging tests have been performed. Experiments have also been designed in climate testing chamber and outdoor in order to evaluate stone recession rate in function of the micro-climate conditions and textural features.

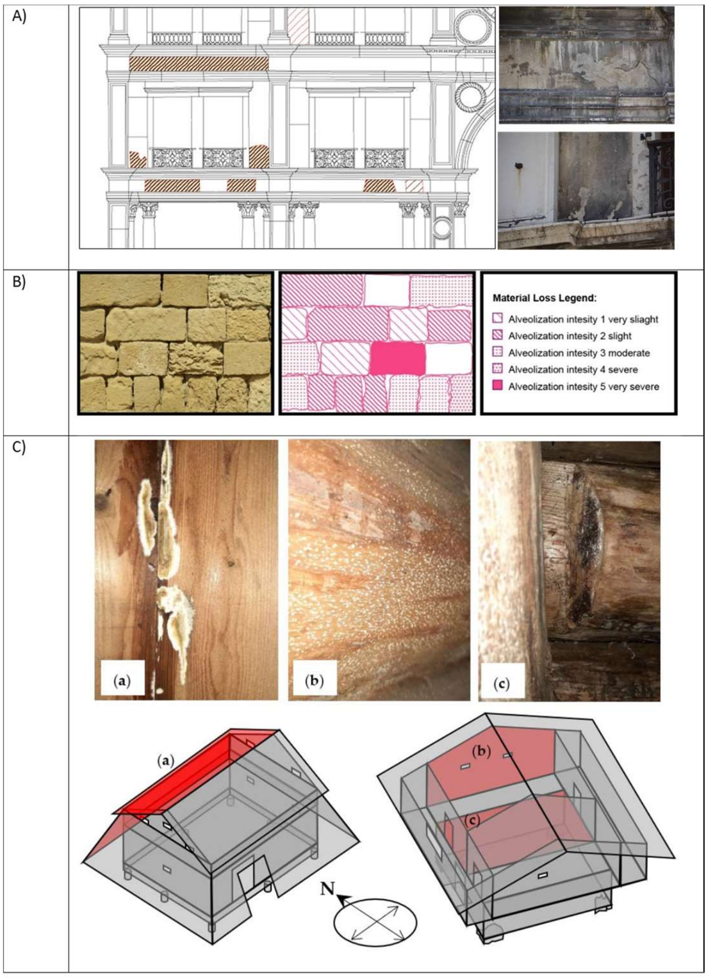
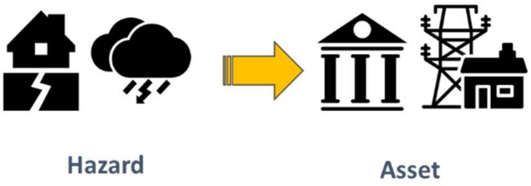


Figure 10: Smart Examples of mapping graphical representations of deterioration patterns: A) Detachments mapping on the Clock Tower of Venice, with details on the blistering phenomena affecting black crusts; B) Example of a mapped area on the Nailac Pier. From left to right: high-resolution image, material loss map, and patterns legend; C) Brown-rot fungi (Coniophora puteana) (a), Scopulariopsis colonies (b) and Myxomycetes (c) detected at the positions highlighted with red color at the Tønsberg Tier 1 Heierstad loft.

5. Implementation of a Hygro-Thermal (HT) simulation tool



Building materials in cultural heritage (CH) sites are subjected to continuous degradation throughout the years. Climatic conditions have a significant impact on the type and rate of deterioration. In addition, the nature of the building materials and their physical, thermal and hygric properties are essential for their response against the decay mechanisms. In order to study the coupled thermal and hygric performance of the building elements in CH sites and buildings a hygrothermal model is needed. Certain variables of the solution of the transient hygrothermal performance then serve as input in damage functions describing various deterioration mechanisms such as mould growth, frost damage, salt crystallization etc. The results from damage functions constitute a quantitative measure of the deterioration risk of CH buildings. Within the HYPERION project the impact of potential future climate conditions and extreme weather events on the deterioration risk of the building materials in CH constructions is examined. Examples of the use of the HT model in the HYPERION solution can be seen in Figure 11 and Figure 12.

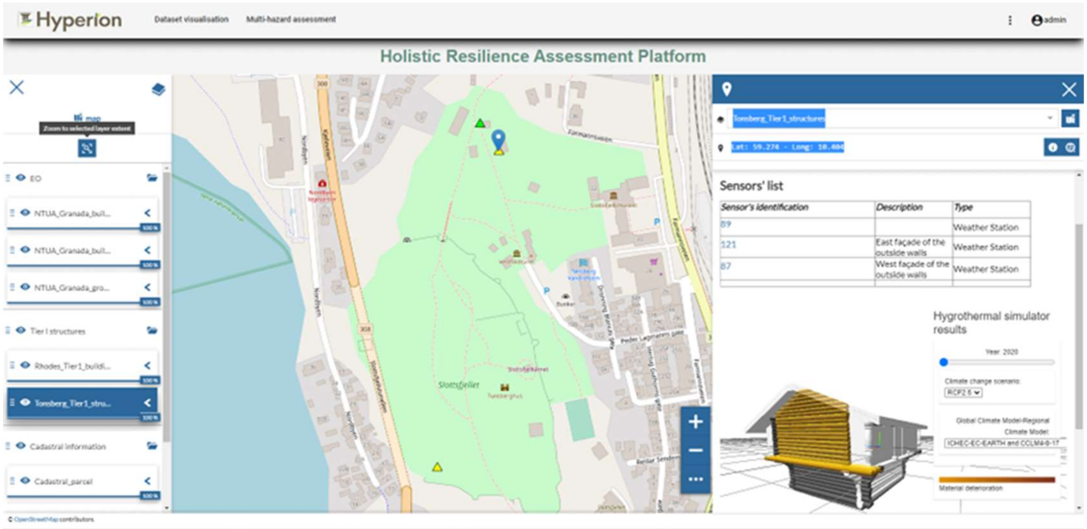


Figure 11: Sensor list and building model visualisation (HygroThermal simulator)

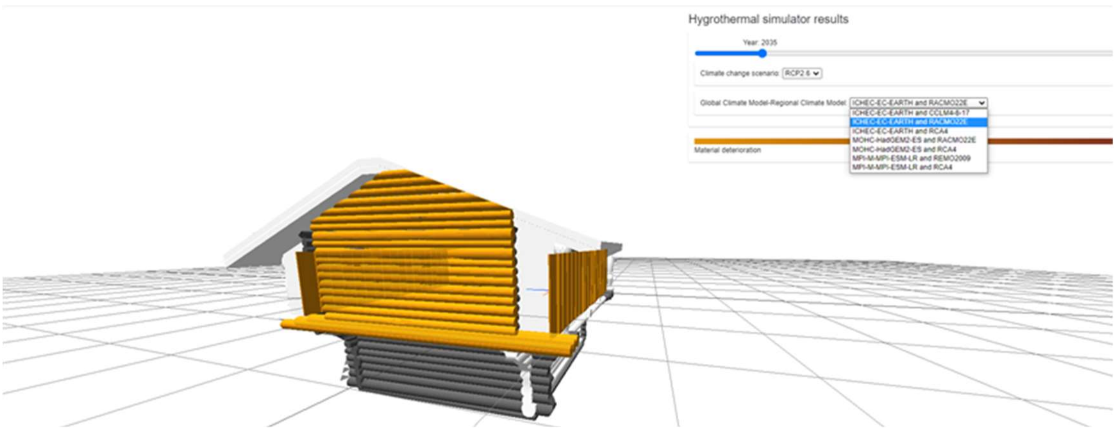
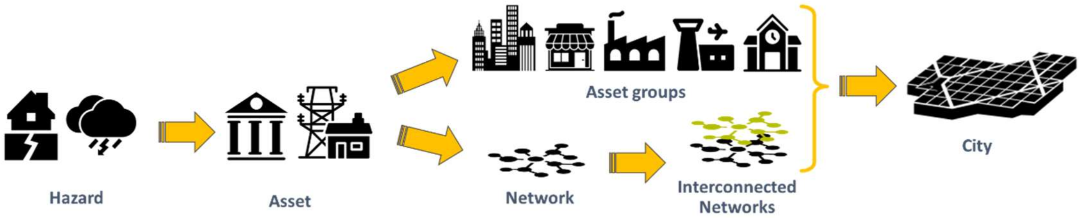


Figure 12: Deterioration of the buildings' materials (HygroThermal simulator)

6. Improved prediction of Structural and Geotechnical (SG) safety risk



The project has developed models to predict direct and indirect impacts of climate, global and environmental change and related risks on historic areas. Improved prediction of Structural and Geotechnical (SG) safety risk of the structures uses simulators that exploit monitoring data from various sensors. Along with the expert knowledge of partners specializing on SG engineering and on materials' deterioration, HYPERION assesses the current condition of structural, non-structural and content components of characteristic archetype buildings in the historic area. These detailed models are then leveraged to validate simplified surrogate numerical models or reduced-order physical models (e.g. Figure 13), achieving accurate pre-event and near-real-time (n-RT) post-event assessment of the impact of the climate pressure and geo-hazards. Related damage/vulnerability functions (e.g. Figure 14) are defined together with capacity thresholds of the aging structure, thus optimising any reconstruction or retrofitting actions and evaluating the response of the structure in the future, for a large number of hazards scenarios with/without the proposed adaptation and mitigation measures.

Putting everything together on a wider area scale, HYPERION uses this approach to enable stakeholders acquire a comprehensive view of the consequences of CC-related or other hazardous events on the entire area of interest, as for example shown in Figure 15 and Figure 16.

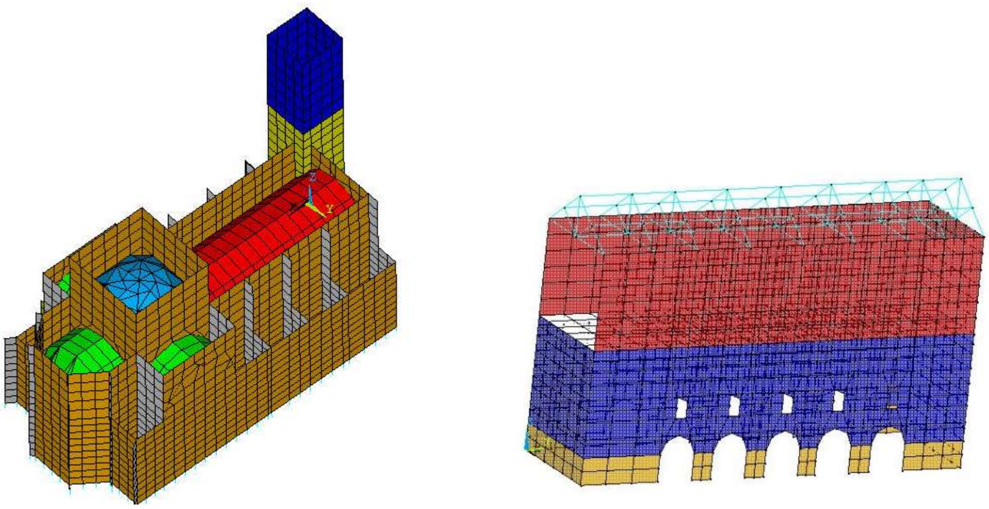


Figure 13: Mesh details of the structural finite element model of: (a) San Jerónimo Monastery, and (b) Mill of the Marquis of Rivas (Granada, Spain).

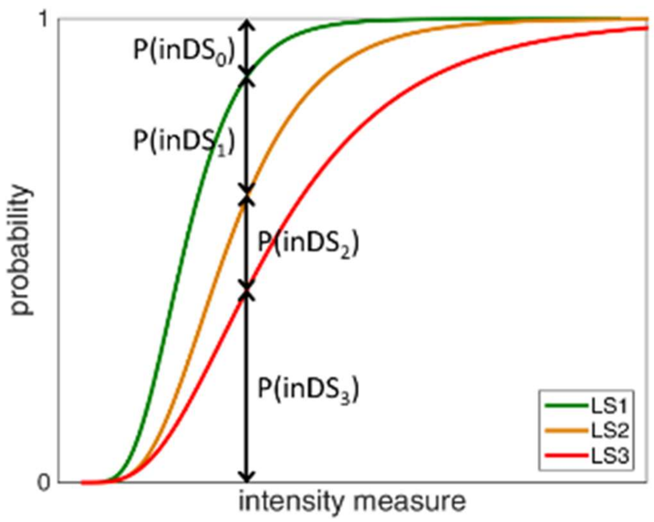
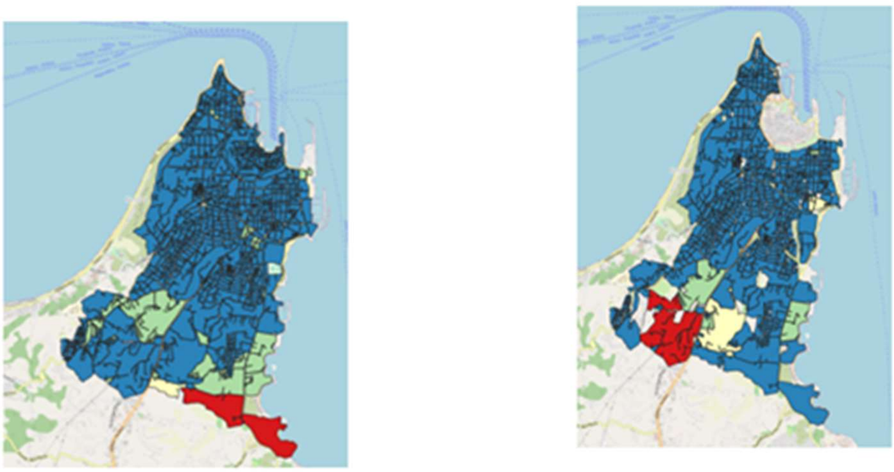
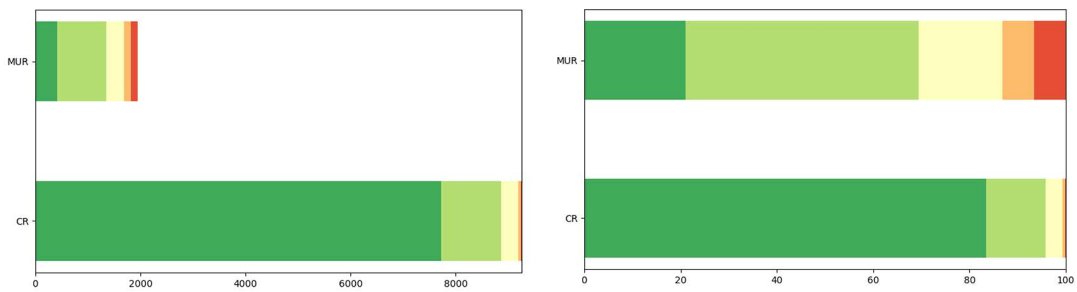


Figure 14: Fragility curves for three sequential limit states. The black arrowed lines indicate the probability of being in each damage state for a certain intensity measure value.



(a) (b)

Figure 15: (a) Consequences for the water network in terms of percentage of people with access to water; (b) Consequences for the Tier 3 buildings in terms of percentage of buildings that collapsed.



(a) (b)

Figure 16: (a) Number of buildings per damage state and typology; (b) Percentage of buildings per damage state and typology.

7. Design of a Holistic Resilience Assessment Platform (HRAP) and a Decision-Support-System (DSS), enabling communities' participation

The HYPERION HRAP platform (Figure 17) allows for the integration of various analysis, modelling tools and damage/vulnerability functions, hence incorporating information from various sources (literature, surveys, satellite, etc.) with different levels of granularity (building/block/regional level) together with the associated uncertainties. All these tools are integrated into a Geographic Information System (GIS), interfaced with existing hazard assessment software and network simulators, and chained to socioeconomic impact analysis tools to produce both quantitative and qualitative loss estimations (e.g. financial loss estimation, etc.) in order to develop an end-to-end simulation platform enabling the running of any number of different "what-if" scenarios.

Figure 17: HYPERION solution Home page

In HYPERION two modes of operation are envisioned in respect to the occurrence of a natural hazard event: the pre-event (or long-term) and post-event (or short-term) operation. The primary difference is that the latter mode is meant to assess the evolving risk as data from the sensors of the monitoring system are implemented into the system, appropriately constraining the scenarios that can be considered, while in the former case all potential scenarios are accounted for. In HYPERION all analyses are performed offline within the SG tool described previously, to avoid having the user buy commercial licenses for structural analysis programs and installing them on his/her own client. This offline execution and storage of millions of results enables (a) obtaining rapid response estimates in milliseconds, versus hours or days that large models need to run and (b) using machine learning to rapidly derive rational response/damage/impact estimates even in cases of hazard scenarios beyond the ones that were initially predicted. Thus, HRAP is directly engaged at all HYPERION phases using pre-computed results to assess the consequences of natural hazard events.

The pre-event operation framework developed for HYPERION is presented in Figure 18. In this phase, all critical assets are identified and their performance is assessed in terms of damage and losses. This requires modelling the critical assets and subjecting them to a number of analyses under a suite of recordings that represent the hazard to which each asset is vulnerable. For instance, an asset vulnerable to the seismic hazard is subjected to a set of ground motion records that are appropriately selected to be consistent to the site-specific seismic hazard, while assets that are under constant barrage of e.g. freeze-thaw cycles, moisture, precipitation, and temperature are subjected to site-specific time-series of the relevant weather parameters that allow assessing their erosion state. Based on analysis results, all potential damage scenarios of each asset are assessed and are co-integrated with the associated consequences in terms of cost, downtime etc. to assess "all" potential damage and consequence realizations for the asset.

This process is repeated for all perils to which each asset is vulnerable and the corresponding results are stored in a database. The ensemble of the consequence files for all assets and hazards affecting them comprise the HYPERION asset impact database.

Within the pre-event phase, stochastic event sets (SESs) are also developed for all hazards threatening the assets, each of them representing a realization of the hazard in the area of interest. For instance, a stochastic event set for the seismic hazard is a possible realization of the seismicity for the given site as described by the site-specific seismic source model. Each stochastic event set comprises a number of IM fields that are potential realizations of the spatially distributed IM values for the given hazard. The IM fields offer spatial correlation of intensity throughout a single event and allow combining compatible asset scenarios to estimate "all" potential damage and recovery realizations for the entire city and CH site, thus assessing the system-level impact. During this phase, sensors are mainly useable within the framework of health monitoring to help us assess the current state of the assets, appropriately calibrate pertinent structural SG detailed models, and use them to derive an updated asset impact database.

The HYPERION post-event operation framework is presented in Figure 19. In this phase the results from a private sensor network are used. The network consists of sensors attached to CH assets that take microclimate condition measurements (e.g. temperature, precipitation, UV power) through interconnected weather stations, smart tags, and accelerometers. In this post-event HYPERION framework phase, the assets' fragility/vulnerability functions can be updated based on data collected through field inspections and available sensor data.

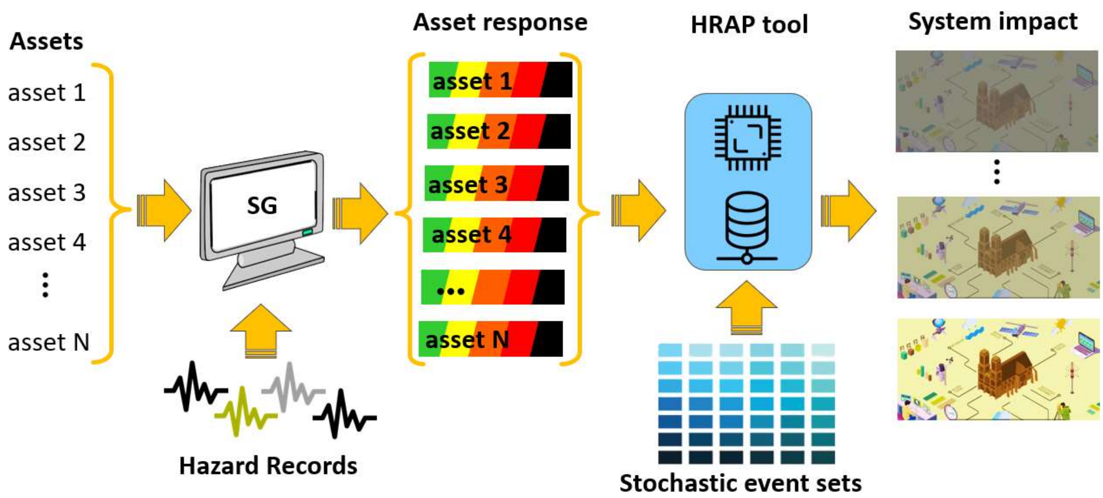


Figure 18: HYPERION pre-event operation mode. All scenarios are still plausible.

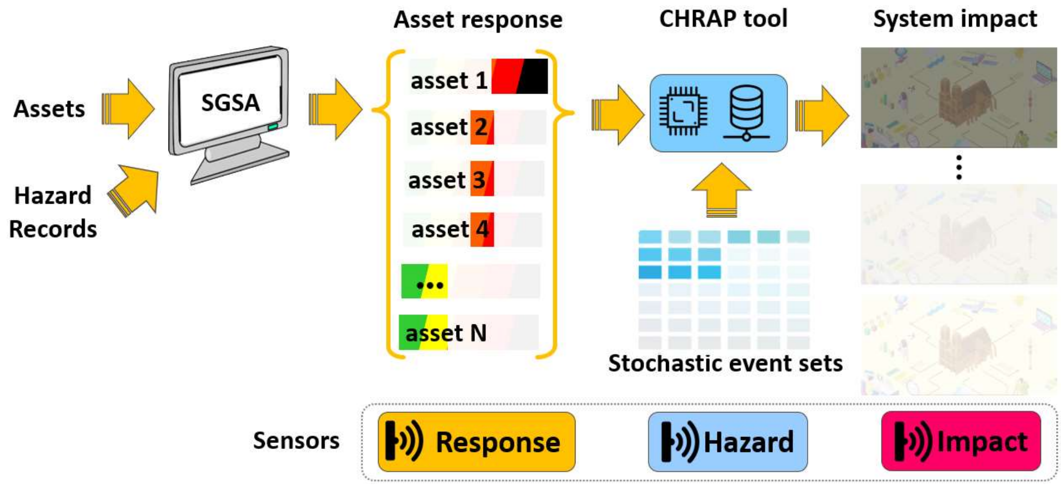


Figure 19: HYPERION post-event operation mode: asset, hazard and impact sensors allow narrowing down the potential outcomes. Greyed-out scenarios are not compatible with sensor input and thus excluded.

Bringing everything together, users (based on their role and access rights) can manage and visualize events through HRAP in the following ways:

- **Operational mode:** In this mode the impact of a real event can be assessed, for which the hazard maps, associated consequences and list of prioritised response activities are determined. (e.g., Figure 20, Figure 21, Figure 22, Figure 23)
- **Short-term planning mode:** In this mode, the impact of any single event ("what if" or "what is") event can be assessed, where the hazard maps, consequences as well as the socioeconomic impact are determined. A list of prioritised response activities is also provided to the user. (e.g. Figure 6, Figure 7, Figure 24, Figure 25)
- **Long-term planning mode:** In this mode, the long-term hazard and consequences are provided to the user for all natural hazards to which each demo-site is vulnerable. (e.g. Figure 5, Figure 26, Figure 27)

The Assessment Module is the technological module that is responsible for merging and evaluating the output from models and visualize this via the UI. For the HYPERION project, it is key to provide the impact assessment results to the local communities and authorities in an interpreted way, paired with mitigation and response actions that will allow them to make educated decisions without struggling with the understanding of complex models and information schemas. Moreover, given that the models and tools can be leveraged for pre-event but also for near-real-time post-event assessment, HRAP aspires to enhance situational awareness at strategic but also at an operational level. The effective and efficient **handling of disparate information and decision levels** is another critical objective that drives the design efforts of HRAP.

Events, either dummy-ones that are created via the HRAP UI or real-ones coming from the middleware services, are provided to relevant endpoints that in turn trigger the publication of results to HRAP. Alerts appear as notifications upon login and all results of events, hypothetical or real, can be explored in the map. In the following paragraphs, HRAP's modes are presented and further explained.

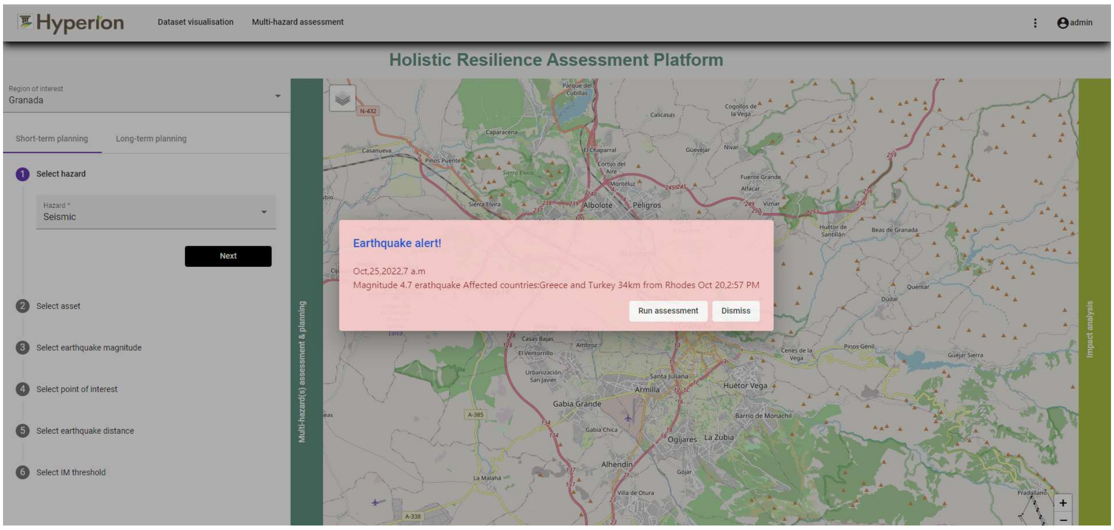


Figure 20: Operational mode - alert

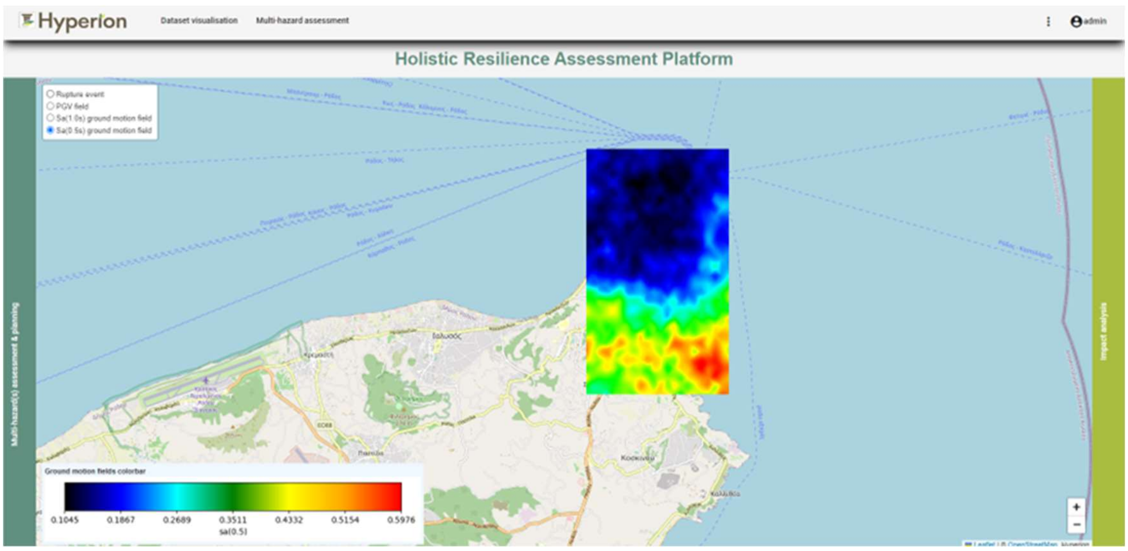


Figure 21: Operational mode - maps

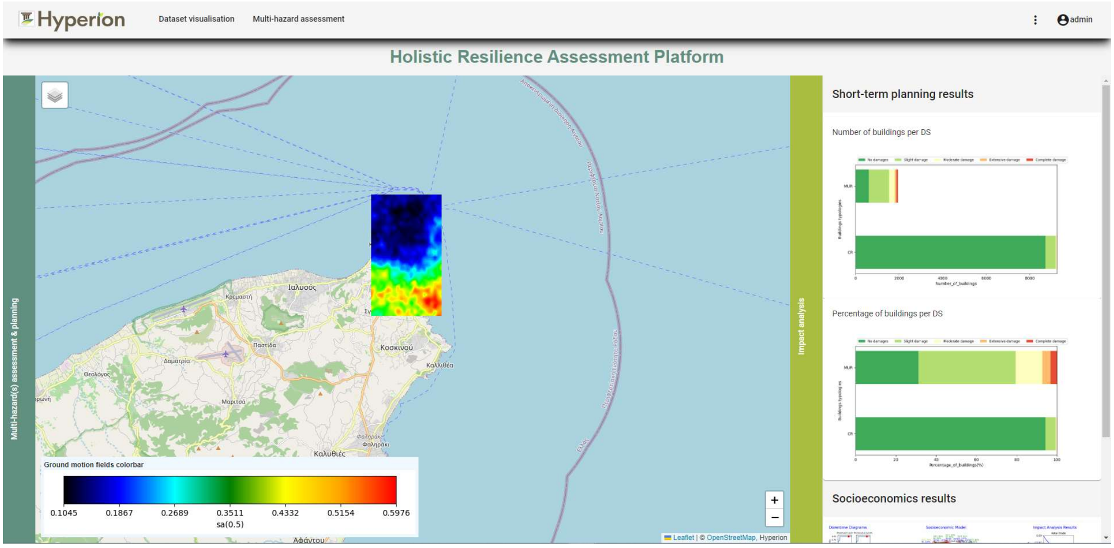


Figure 22: Operational mode – Tier 3 building taxonomy and damage state

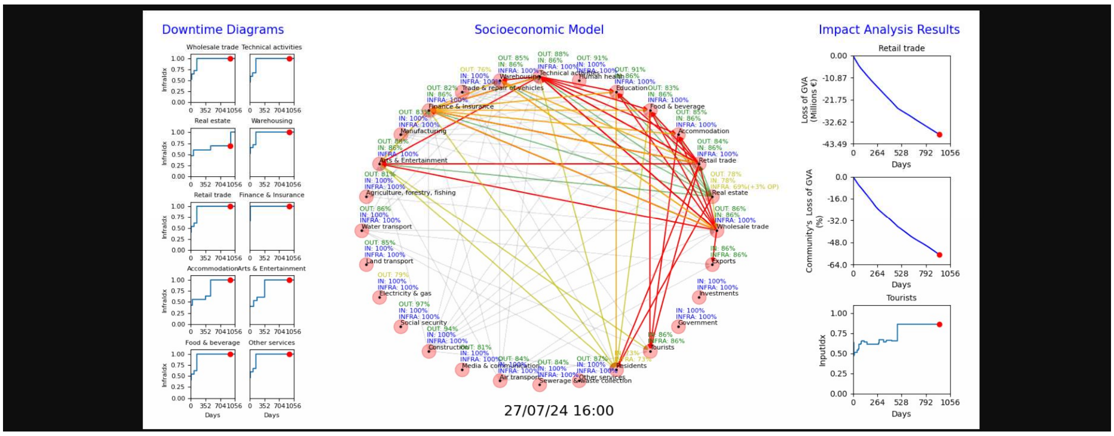


Figure 23: Operational mode – Socioeconomic impact

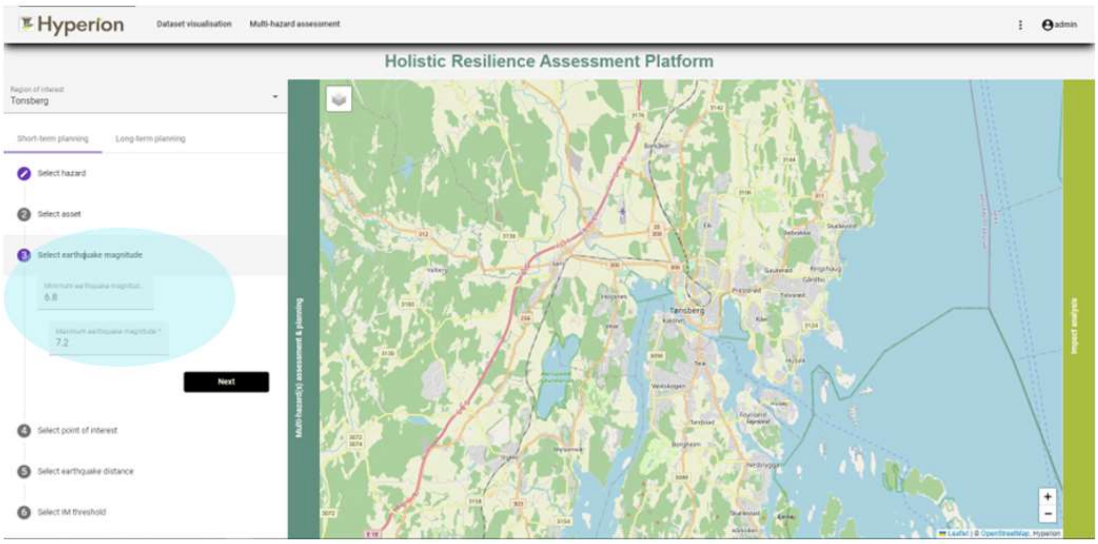


Figure 24: Short-term planning options (Select earthquake magnitude option)

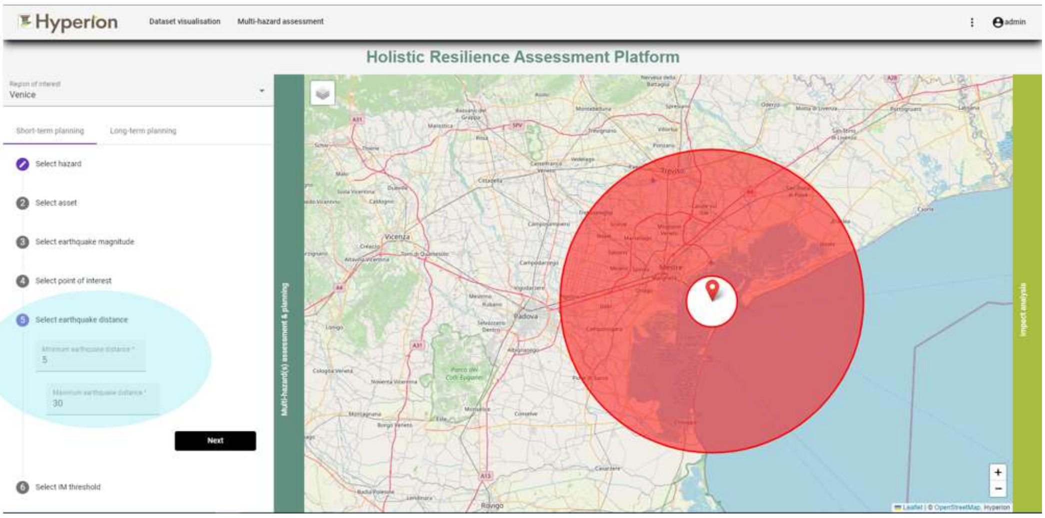


Figure 25: Short-term planning options (Select point of interest option)

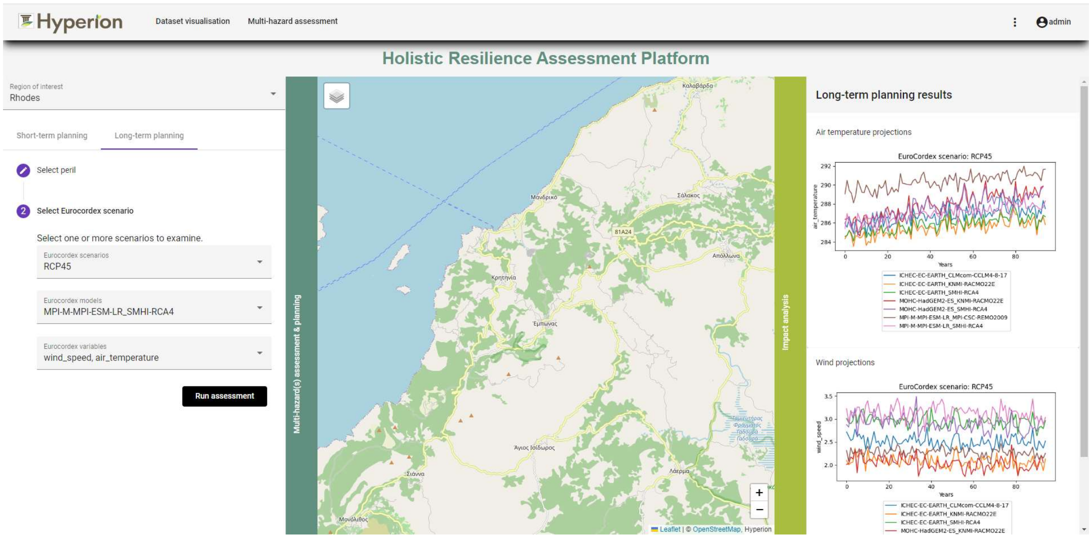


Figure 26: Long-term planning – EuroCordex projections

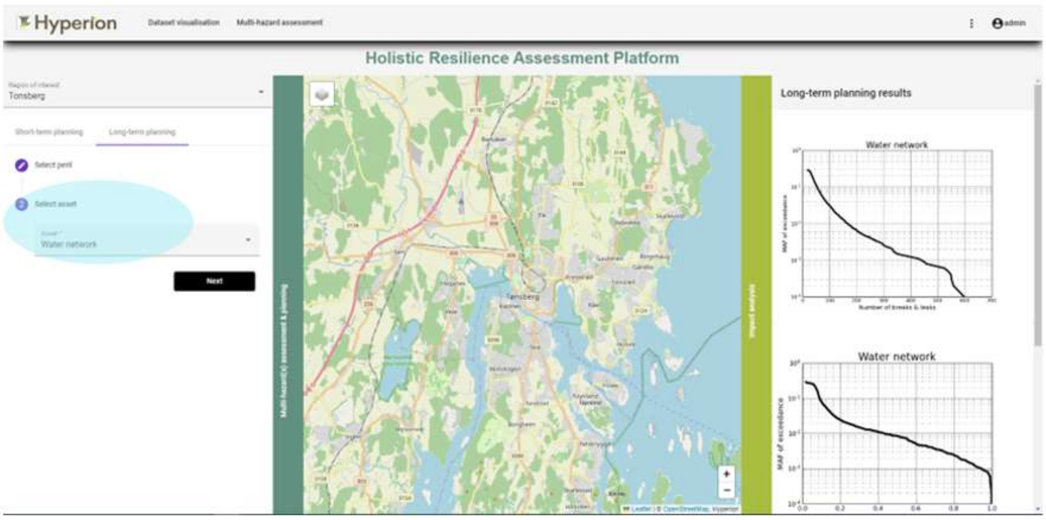


Figure 27: Long-term planning – Water network consequences

Finally, Users can view reports and information provided by residents though the Communities' Engagement ICT Tool (Figure 28 and Figure 29). After collecting user feedback from the tool, users can validate model results and/or take corrective actions (if needed).

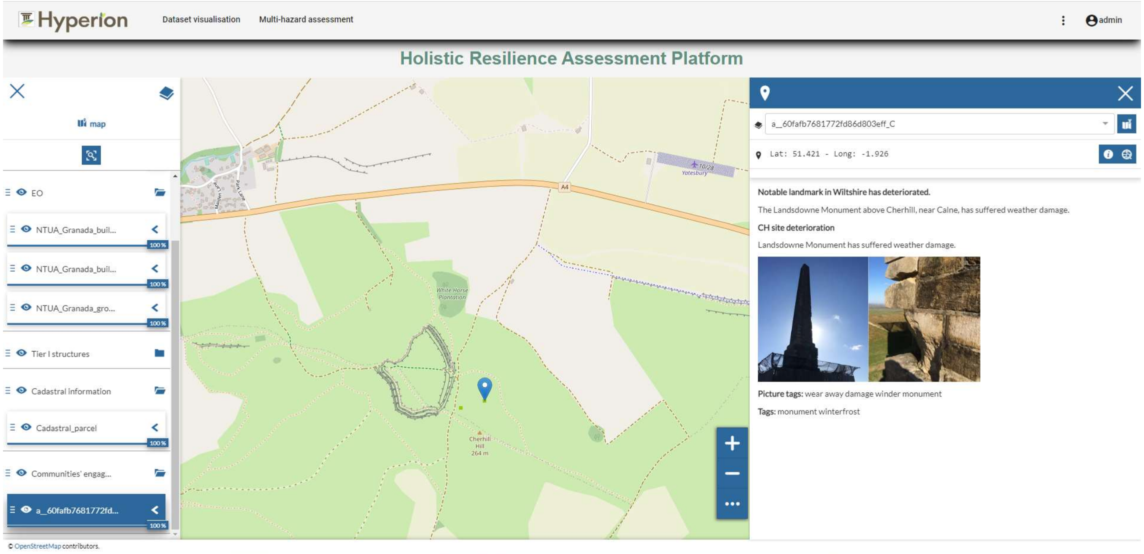


Figure 28: Communities' Engagement Tool

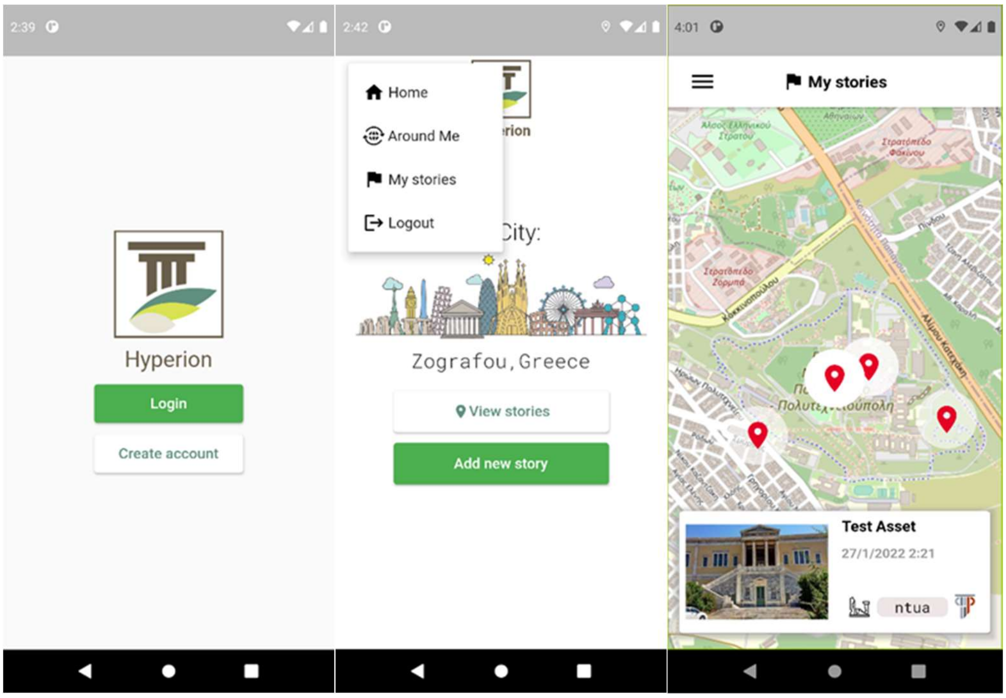


Figure 29: Screenshots of the Hyperion Mobile Application dashboard

2.2 Proper adaptive response strategies for CC and other hazards scenarios

Natural (e.g., earthquakes, floods) and man-made (e.g., water contamination, explosions, fires) perils that have occurred recently worldwide have demonstrated that even modern societies remain vulnerable to extreme hazard events, and consequently they are prone to direct and/or indirect losses affecting the communities and their support systems. Direct impacts consist of damages to premises, equipment, vehicles, inventories, and eventually to human injuries or even fatalities. From an economic standpoint, the **direct cost** of an event is the repair or replacement cost of the damaged or destroyed assets, respectively and it is commonly estimated by insurance companies following the occurrence of a disaster[4]. On the other hand, the **indirect cost** comprises the off-site business interruption, reduction in property values and stock market effects[5]. With reference to CH sites, indirect costs can be substantially amplified if the catastrophic event occurs during the so called “high season”, since the annual income of the majority of the nearby or otherwise associated to the CH site businesses relies more on the tourism rather than the local consumption.

On account that not all threats can be averted[6], enhancing the resilience of a community through preparedness and adaptation measures comprises the state-of-the-art approach to minimize the direct and indirect costs of a catastrophic event. Due to its multifaceted nature, resilience has been a buzzword that is used by a great deal of scientific fields, and thus a variety of definitions can be found in the pertinent literature. According to Cimellaro et al.[6], community resilience can be decomposed into seven dimensions: (i) population and demographics, (ii) environment and ecosystem, (iii) organized government services, (iv) physical infrastructure, (v) lifestyle and community competence, (vi) economic development, and (vii) social-cultural capital. The same authors use a simple mathematical definition of resilience, which is graphically illustrated in Figure 30.

In other words, resilience of an historic area refers to the measurable capability of the historic area to bounce back and recover from a disruptive natural hazard event. This capability is quantified based on metrics of physical damage, direct & indirect monetary losses, especially focusing on the Gross Value Added (GVA, which

[4] Hallegatte S. (2008). *An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina*, Risk Analysis, **28**(3), 779-799. https://doi.org/10.1111/j.1539-6924.2008.01046.x

[5] Kaushalya H., Karunasena G., Amarathunga D. (2014). *Role of insurance in post disaster recovery planning in business community*, Procedia Economic and Finance, **18**, 626-634. https://doi.org/10.1016/S2212-5671(14)00984-8

[6] Cimellaro G.P., Renschler C., Reinhorn A.M., Arendt L. (2016). *PEOPLES: A framework for evaluating resilience*, Journal of Structural Engineering, **142**(10). https://doi.org/10.1061/(ASCE)ST.1943-541X.0001514

characterizes the economic output of the community) and evaluating it over the dimension of time.

HYPERION is able to provide insights to decision making and response strategies by generating a socioeconomic model for quantifying the impacts of catastrophic events on the community level of CH areas as well as to simulate their post-event restoration process. The proposed model is designed to be holistic but also expandable, allowing for easy-to-implement modifications to accommodate the specific conditions at the considered CH site or integrate newly obtained information. Once the initial input data are collected to feed the tool, the developed methodology allows almost effortlessly to run pre-event "what-if" scenarios to undertake an initial rapid post-event analysis for assessing the socioeconomic impacts of adverse events on a community level. The assessment could be constantly updated with newly obtained data along with the outcomes of ongoing background simulations so as to always deliver accurate and up-to-date output. Ultimately, the proposed tool is anticipated to assist the CH operators and managers, cultural authorities, policy makers, etc. towards assessing the overall resilience of an entire CH area, considering both its assets and users/inhabitants.

An example of stakeholder facilitation in prioritizing actions and planning for response strategies using the HYPERION platform can be seen for the city of Rhodes (Figure 31, Figure 32), where an extreme event showing to affect primarily accommodation services, has severe consequences also in the wholesale sector, which are not expected to bounce back for a period of at least 90 days. A more detailed description of guidelines and techniques for mitigating these effects is presented in section 2.7.

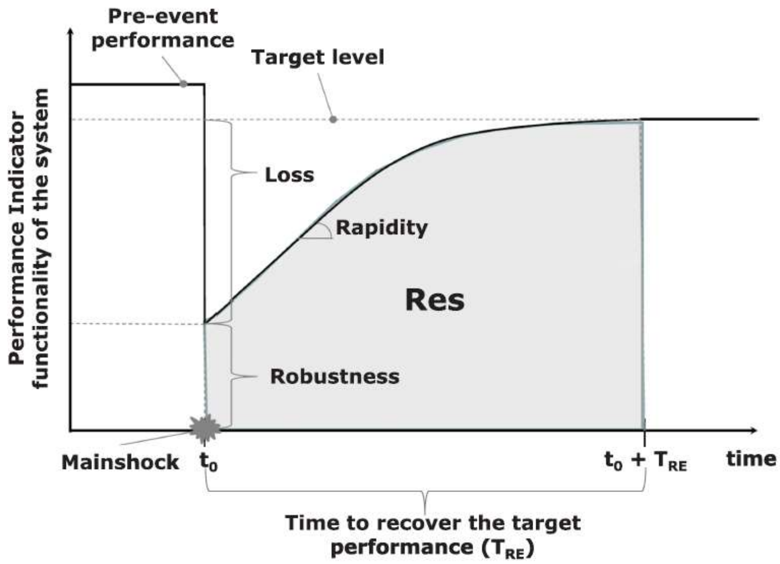


Figure 30: Definition of resilience metrics.

Business	Units	GVA (mill. €)	GVA (%)
"Hotel AA"	1	10.51	4.0
"Motel BB"	1	3.22	1.2
"Motel AB"	1	1.49	0.6
"Hotel AC"	1	7.82	3.0
…	…	…	…
"BnB BC"	2	6.67	2.5
Total	58	262.96	100

Figure 31: Derivation procedure of the "Accommodation" business sector for the city of Rhodes, combining the GVAs and capacities of different lodging firms.

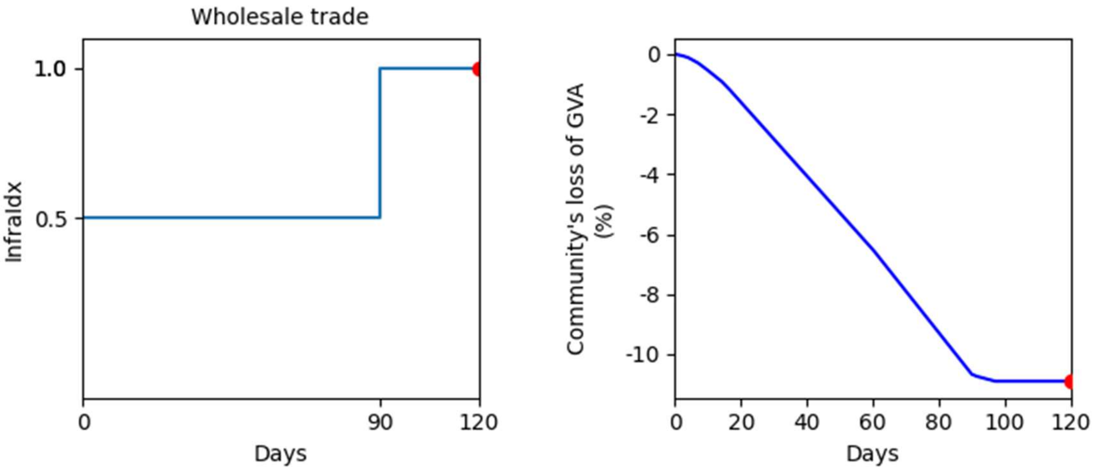


Figure 32: Example of Sector Shutdown Analysis (SSA) for the "Wholesale trade" sector.

2.3 Post-disaster reconstruction example

At least 250 natural disasters and 125 human-made catastrophes occur each year in the modern world[7]. In recent decades, the number of disasters has increased steadily and so has their toll of losses, damage, destruction, and casualties[8]. Recovery after disaster is thus a perennial problem of growing complexity. The traditional view of reconstruction is a rather uninventive one of picking up the pieces after a devastating event and thus restoring the status quo ante. However, by creating sustainable disaster mitigation, reconstruction can be used as a catalyst to improve people's lives and make communities safer[9]. Following this line of thought, HYPERION has prioritized its resources to produce a tool which will give practical insights on available decisions and financial tools to mitigate risks, and guidelines for understanding the socioeconomic impacts of decision making.

Consider for example a scenario where a severe event has occurred in the city of Rhodes. HYPERION provides both short-term and long-term tools to assess the situation and facilitate reconstruction. In the aforementioned example, the short-term tool provides results only for the seismic hazard, as damages induced from weather, for the case of CH buildings, are not acute but chronic, i.e., long term. The short-term impact assessment tool allows the user to assess the impact of any seismic event by combining pre-computed hazard scenarios, consequence realizations, and the exposure model of the city of interest (Rhodes, Granada). The intensity of the seismic hazard is pre-calculated and provided as input to HRAP in the form of Stochastic Event Sets (SES) and ground motion fields (GMF).

At first, the user defines the parameters of the seismic scenario of interest, such as the minimum/maximum magnitude and minimum/maximum distance of the epicenter from a reference point and the events that fulfill the given criteria are returned from the multitude contained in the site-specific SES. The intensity of the seismic hazard is pre-calculated and provided as input in the HRAP. Any of those events can be selected, and their rupture location and the corresponding GMFs are returned and shown to the user (Figure 7). The consequences of the given event are determined for all critical assets as for instance shown in Figure 16 where the bar charts show the distribution of buildings belonging to different damage states.

The long-term impact assessment tool provides annualized consequences for the seismic and the weather-related hazard by considering also the impact of CC.

For the Tier 1-2 structures the fragility curves are produced for two states, one of no deterioration (as built) and a deteriorated state corresponding to the present time, as well as the year 2100. Such buildings are affected by CC and their vulnerability

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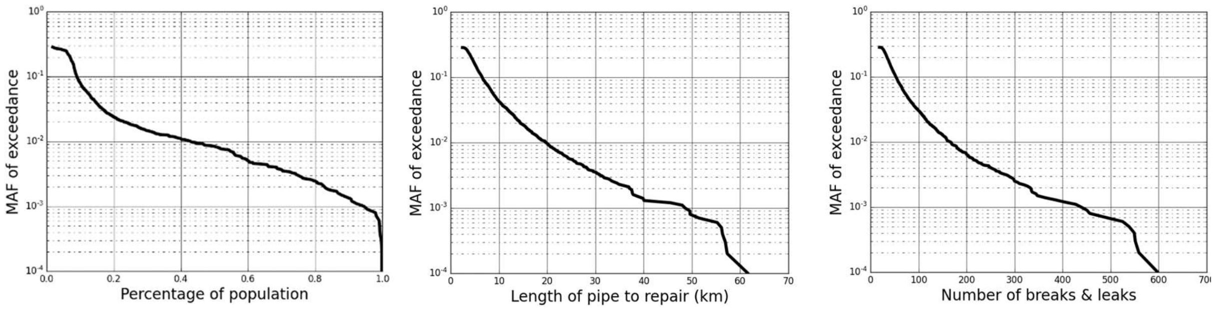
[7] ISDR 2002. Living With Risk: A Global Review of Disaster Reduction Initiatives. Inter-Agency Secretariat of the International Strategy for Disaster Reduction, Geneva. As the definition of 'disaster' is controversial, the number of events recorded varies from one source to another.

[8] Munich Re Group 2002. Topics. Annual Review: Natural Catastrophes 2001. Munich Re Group, Munich. Some of the increase is the result of improved recording of catastrophes and changes in accounting methods, but there is not doubt that the toll of disasters is increasing.

[9] Cuny, F.C. 1983. Disasters and Development. Oxford University Press, New York

increases due to deterioration. Appropriate graphs present the recession rate of their main material, like the calcarenite stone in Granada and the bricks in Venice. The recession rate graphs are produced and are calculated for all different scenarios and models of EUROCORDEX using experimental formulas. In addition to this, the risk assessment for the portfolio assets and the network is calculated.

Overall, for the seismic hazard, the tool provides the mean annual frequency of exceedance (MAF) of different consequences, namely the percentage of population with no access to water, the length of pipes need repairing, the number of breaks of pipes, the direct cost for the portfolio assets and the number of buildings for each damage state (see Figure 33, Figure 34, Figure 35). The corresponding hazard maps are also determined. Together with the results of the risk assessment, the direct losses for the city and the loss of functionality are also determined, allowing the computation of the socioeconomic impacts. These are based on the damages to different sectors of business, accounting for the indirect losses.



(a) (b) (c)

Figure 33: MAF for the water network (a) Percentage of population without access to water, (b) Length of pipe to be repaired (km), (c) Number of breaks and leaks.

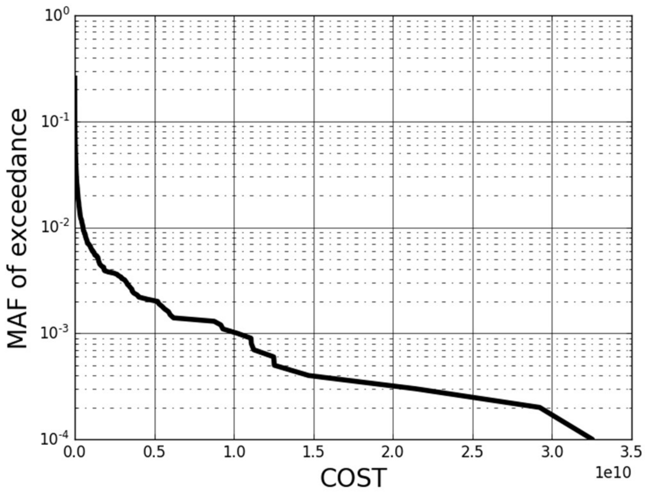
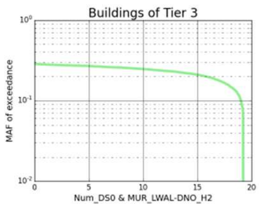
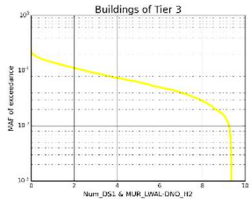


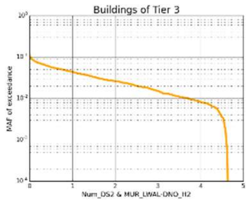
Figure 34: MAF for the Tier 3 buildings of Rhodes.



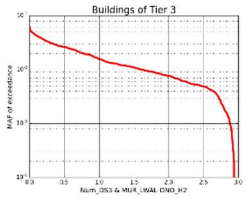
(a)



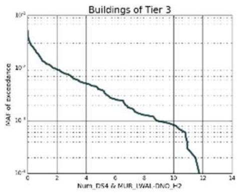
(b)



(c)



(d)



(e)

Figure 35: MAF for the Tier 3 buildings per DS and typology (a) DS0: No damage, (b) DS1: slight damage, (c) DS2: Moderate damage, (d) DS3: Extensive damage, (e) DS4: Collapse damage.

2.4 Practical checklists and references

Standard Response Procedures comprise sets of pre-defined actions needed to be undertaken by an organization when its normal operations have been interrupted by an adverse event. Such protocols are essential components of a Business Continuity Plan as, when executed successfully, they can enhance business resilience by accomplishing the following objectives: (a) protect the disrupted facilities/departments from further damages, (b) prevent propagation of failure to the non-disrupted facilities/departments, and (c) hasten the post-event recovery processes. Standard Response Procedures can be a part of organization’s Emergency Response Plan, which delineates the management of resources and responsibilities to achieve objectives (a) and (b). In addition, Standard Response Procedures may also correspond to the Recovery Plan of an organization, which comprises strategic guidelines for rapid post-event recovery, by defining the priority at which critical facilities of the organization should be restored.

Accordingly, the concept of Standard Response Procedures can be extended for larger systems like CH communities, states, or even countries. Therein, resilience objectives (a) and (b) are handled by the so-called Community Emergency Plan[10], which refers to the actions undertaken by the involved agencies (e.g., CH managers, local/regional authorities, Member States) to mitigate the immediate aftermaths of a disaster and ultimately protect human life. Such actions involve management and deployment of first responders (e.g., policemen, firefighters, emergency medical technicians), early warning and information of citizens at-risk, restoration of critical infrastructure and lifeline services (e.g., roads, bridges, electricity network), etc. Community Emergency Plans are typically designed and executed by the pertinent civil protection mechanism of the community (e.g., the ministry of climate crisis and civil protection), which has a deeper understanding of its actual needs and weaknesses during a crisis.

HYPERION deals with the post-disaster restoration process of a CH community (i.e., objective (c) of the Standard Response Procedures), by utilizing a quantitative methodology to assess the effectiveness of several Community Recovery Plans. This allows municipal authorities or external actors (e.g., insurance companies, federal government) to derive a funding prioritization strategy based on the economic importance of the critical business sectors operating within the CH community. For this purpose, the proposed Funding Prioritization Analysis (FPA) utilizes HYPERION’s proprietary socioeconomic model to estimate actual economic losses due to supply and demand outages.

The Funding Prioritization Analysis (FPA) is discretized into a series of hypothetical “what-if” scenarios named Sector Shutdown Analyses (SSAs). Each SSA comprises the reduction of the production capacity of a selected business sector by a certain magnitude (e.g., by 50%) and a certain time duration (e.g., three months), while the rest business sectors are assumed to be fully operational in terms of facility and

[10] Perry R.W., Lindell M. K. (2003). *Preparedness for Emergency Response: Guidelines for the Emergency Planning Process*, Disasters, **27**(4), 336–350. https://doi.org/10.1111/j.0361-3666.2003.00237.x

infrastructure disruptions. Consequently, the socioeconomic model developed and integrated into the Holistic Risk Assessment Platform (HRAP) engine of HYPERION is employed to derive the estimated total indirect losses of the community for each SSA. Finally, based on these total community losses, the involved agencies can derive the aforementioned hierarchy of criticalities and use it to settle an objective fund prioritization strategy. The key steps of the proposed FPA are showcased in the socioeconomic model of the city of Rhodes by assuming three levels of Business Continuity Strategy (BCS) exploitation for each critical business sector, to highlight the effect of the BCSs to the robustness and rapidity of the entire CH community.

In the aforementioned example of Rhodes, HYPERION would produce the FPA results shown in Figure 36 for low community resilience, in which the local businesses could not exploit any overproduction capacities to increase their functionality after a catastrophic event. Figure 37 and Figure 38 show the corresponding results in case of medium and high community resilience, accordingly. It is noted that business sectors that correspond to intra-community critical infrastructure and lifeline services, such as human health, water and power distribution, waste disposal, etc. were disregarded. Essentially, their importance to the local community of Rhodes is so high that the regional/municipal authorities should always prioritize their rapid restoration. On the other hand, the water and air transportation infrastructure were included in the FPA, as the marine port and the airport were considered as components of the supply chain whose functionality does not directly impact the critical operations inside the city of Rhodes.

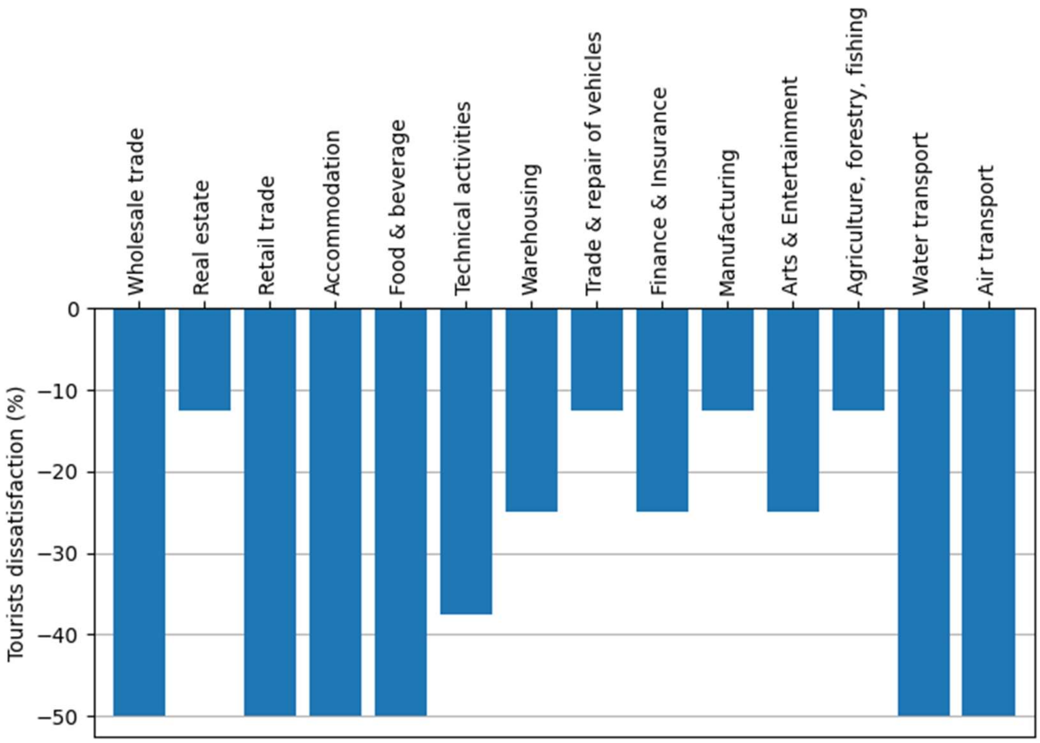


Figure 36: Bar charts from the SSAs conducted for the city of Rhodes, showing the maximum tourist dissatisfaction (low community resilience).

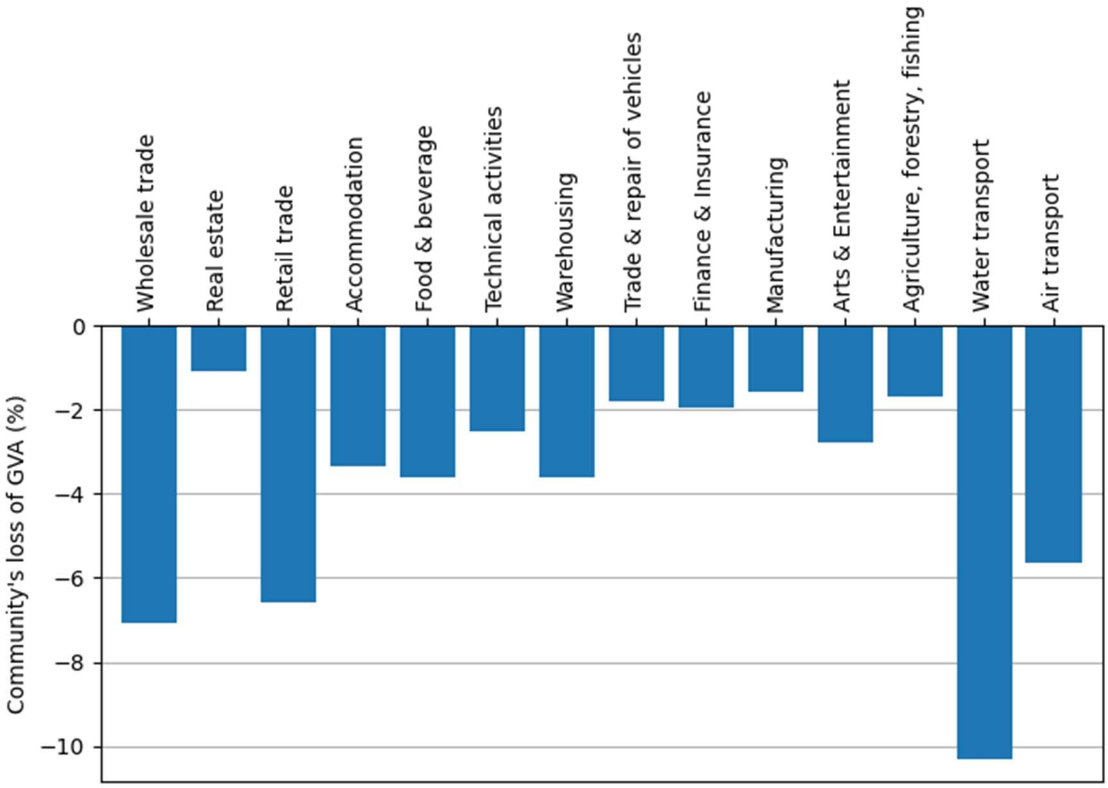


Figure 37: Bar charts from the SSAs conducted for the city of Rhodes, showing the total community indirect losses (high community resilience).

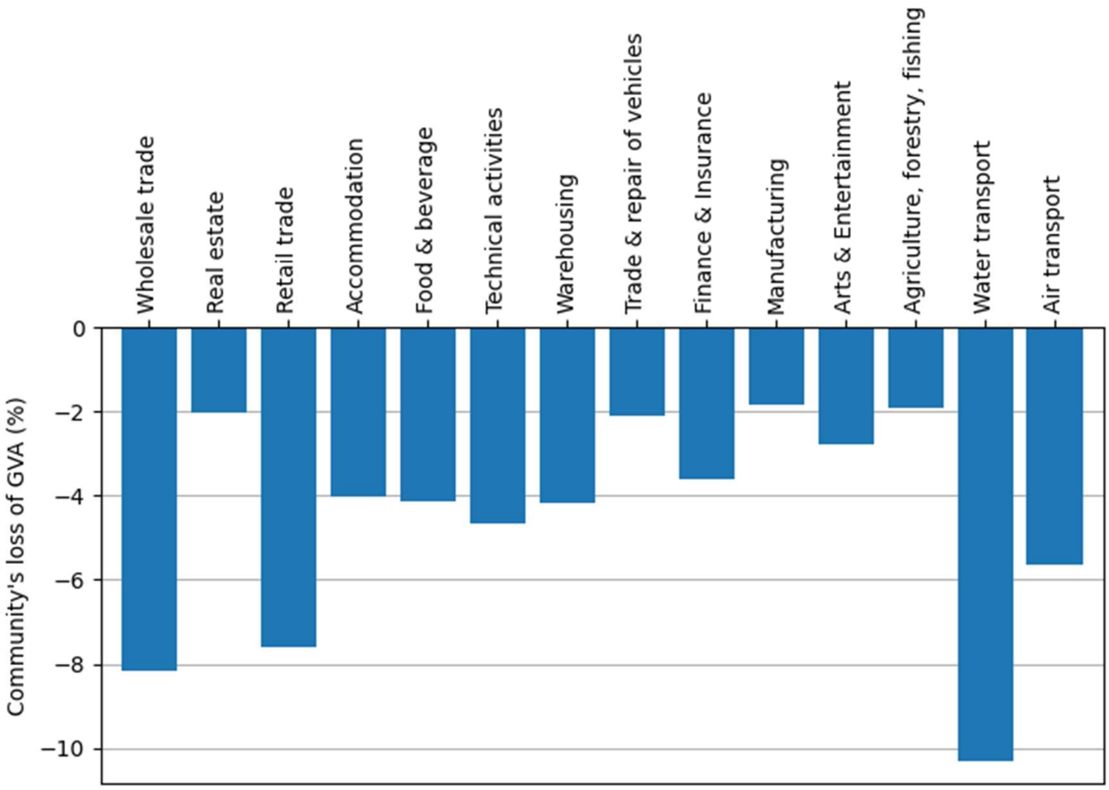


Figure 38: Bar charts from the SSAs conducted for the city of Rhodes, showing the total community indirect losses (moderate community resilience).

2.5 Recovery requirements for various sectors

As stated above, critical infrastructure and lifeline services, such as human health, water and power distribution, waste disposal, should be prioritized at the highest possible level, in order not to directly impact the critical operations inside the city.

Regarding the rest of the business sectors of a CH area, their capacity to absorb the initial shock, respond, and adapt in order to maintain its functionality and hasten recovery[11], i.e., its resilience, the socioeconomic model employs for each sector an index that is called performance index (*PerfIdx*). Herein, *PerfIdx* is defined as the ratio between the reduced GVA of the business sector following the occurrence of a hazard event and its GVA under ordinary operating conditions. Evidently, *PerfIdx* is a multi-variant time function that depends not only on the operability of the considered business sector, but also on the socioeconomic impacts of the disaster on the CH site. To depict the individual socioeconomic factors affecting the performance of a business sector, *PerfIdx* is discretized into three distinct components:

a) The infrastructure index (*InfraIdx*), which measures the reduced production/service capacity of a business sector due to "infrastructure damages". As infrastructure damages we define herein all the factors that hamper the operability of a business unit except supply outages, as those are treated separately by the *InputIdx*. Therefore, *InfraIdx* is calculated as the percentage of the fully operating business units belonging to a particular business sector at a given time step.
b) The input index (*InputIdx*), which captures the propagating effect of supply outages, according to the so-called, Vendor Dependence Tables (VDTs). VDTs are tools frequently used in Business Continuity to evaluate the dependence of an organization to its vendors. Assuming that the organization has *N* vendors, its corresponding VDT comprises *N* lines, where each line contains a series of indices that capture the progressive (over time) loss of productivity of the investigated business sector due to complete supply disruption from a particular vendor, ranging from 1 (to denote full productivity) to 5 (to denote no productivity). VDTs can also be defined for FDNs, expressing their adaptive consumption behaviour to disturbances on essential supplies and services (e.g. Figure 39).
c) The output index (*OutputIdx*), which measures the propagating reduction of the demand during the recovery phase. *OutputIdx* is mainly related to (i) the intermediate business-to-business consumption and (ii) the FDN demand (e.g., tourists, residents, etc.). Herein, both components (i) and (ii) are considered by propagating the reduced demand via a so-called Input-Output Table (IOT).

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[11] Franchin P., Cavalieri F. (2014). *Probabilistic assessment of civil infrastructure resilience to earthquakes*, Computer-aided Civil and Infrastructure Engineering, **30**. https://doi.org/10.1111/mice.12092

Finally, at each time step, a distinct set of (*InfraIdx*, *InputIdx*, *OutputIdx*) is calculated for each business sector, following a hybrid (macro/microscopic) methodology to account for cascading failures and socioeconomic impacts.

Based on the total community losses estimated for each SSA, one can derive the aforementioned hierarchy of criticalities and use it to settle an objective fund prioritization strategy. In the example of the historical city of Rhodes, the FPA highlighted that the most critical sectors were related to the key elements of the supply chain, namely the marine port, airport, wholesale, and retail. Moreover, important B2B sectors were also found to play a significant role in the functionality of the entire CH community. By considering a moderate or high resilience community framework, the importance of the marine port became the dominant infrastructure that could potentially lead to the complete paralysis of Rhodes' economy. In general, high level of business resilience were ascertained to enhance the response of the entire community to CC or non-CC perils, as reconstruction funds could be efficiently concentrated into the restoration of specific critical assets, ultimately enhancing community's robustness and rapidity.

#	Retail trade	0h	1h	2h	4h	8h	12h	1d	2d	4d	1w	2w	1mo	2mo	∞
3	Retail trade, except of motor vehicles and motorcycles	5	5	5	5	5	5	5	5	5	5	5	5	5	5
8	Business, scientific and technical activities	1	1	1	1	1	1	1	2	2	3	4	5	5	5
11	Financial services and insurance activities	1	1	1	1	1	1	1	2	2	3	3	3	4	5
1	Wholesale trade, except of motor vehicles and motorcycles	1	1	1	1	1	1	1	2	3	4	5	5	5	5
12	Manufacturing	1	1	1	1	1	1	1	1	1	1	1	2	2	2
14	Agriculture, forestry, fishing	1	1	1	1	1	1	1	1	1	1	2	2	2	2
2	Real estate activities	1	1	1	1	1	1	1	1	1	1	1	1	2	2
10	Trade and repair of motor vehicles and motorcycles	1	1	1	1	1	1	1	1	1	1	2	2	2	3
19	Construction	1	1	1	1	1	1	1	1	1	1	1	2	2	2
4	Accommodation	1	1	1	1	1	1	1	1	1	1	2	2	3	3
5	Food and beverage services	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	Education	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	Warehousing and support activities for transportation	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	Creative, arts and entertainment activities	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	Water transport	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21	Air transport	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23	Other services	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	Human health and social work activities	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	Land transport and transport via pipelines	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	Electricity, gas, steam and air conditioning supply	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18	Public administration and defense; compulsory social security	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	Media and communication	1	1	1	1	1	1	1	1	1	1	1	1	1	1
22	Sewerage, waste collection, treatment, etc.	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 39: Example of a Vendor Dependence Table for the "Retail trade" business sector.

2.6 Financial tools to mitigate risk

A comprehensive disaster risk management strategy is essential for mitigating the impact of severe hazards and protecting valuable cultural heritage, since it facilitates resource mobilization for efficient disaster response and minimizing long-term financial consequences. Within the context of the EU-funded project Hyperion, we provide examples of such a strategy on the cities of Rhodes and Granada, which possess significant cultural assets that are susceptible to seismic hazards. We investigate the implementation of ex-ante financing options, such as risk retention and transfer mechanisms, utilizing a risk layering approach to optimize financial risk management strategies. By tailoring these strategies to stakeholders' unique needs and risk-bearing capacities, our research contributes to effective disaster financial risk management for earthquake-prone areas.

Risk management ex-ante financing options (Figure 40) encompass two primary approaches: risk retention and risk transfer mechanisms. Risk retention involves setting aside resources, such as contingency funds or individual/shared reserves, to be utilized immediately after a disaster occurs.

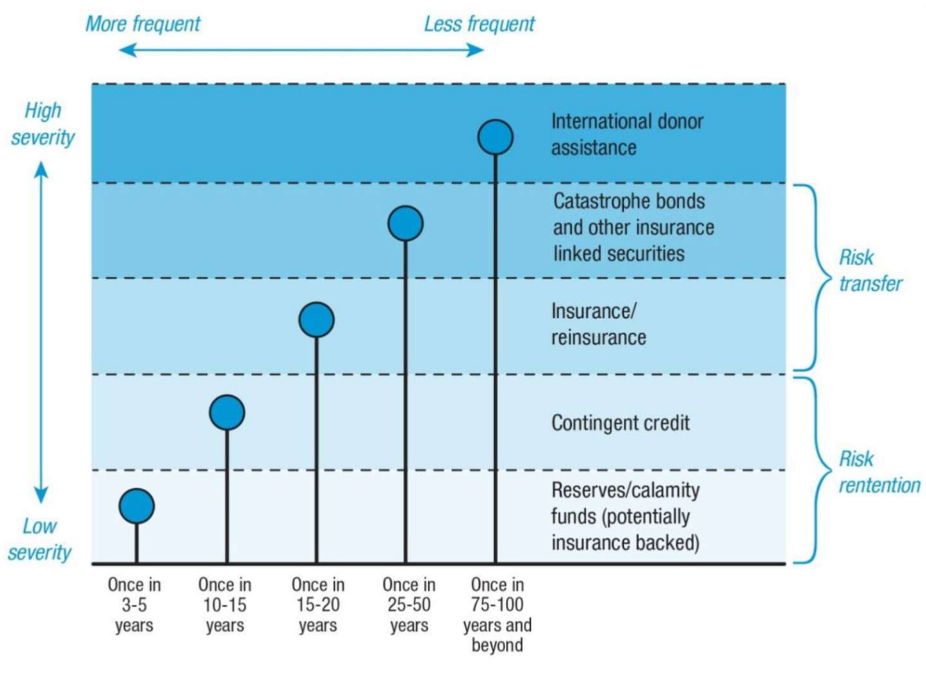


Figure 40: Risk management ex-ante financing options[12]

While risk retention provides immediate access to funds without incurring additional costs, it poses the challenge of maintaining these reserves indefinitely, incurring an opportunity cost of tying up a certain amount of money for an indefinite period. Risk

[12] Lydia Poole, A Calculated Risk. How Donors Should Engage with Risk Financing and Transfer Mechanisms, OECD DEVELOPMENT CO-OPERATION WORKING PAPER 17, July 2014

retention is particularly suitable for high-frequency, low-severity risks, where the potential short-term losses can be covered by available reserves.

On the other hand, risk transfer mechanisms shift financial risk to third parties, such as insurance companies or capital markets. Insurance, as a form of risk transfer, offers reduced volatility and alleviates liquidity concerns. However, it comes with the price of premium payments. Insurance and reinsurance are especially suitable for low-frequency, high-severity losses where significant liquidity is required. The infrequency of such events ensures that the premiums charged remain reasonable.

One specific form of risk transfer, parametric insurance, deserves attention due to its usefulness in natural disaster scenarios. Parametric insurance triggers pay-outs based on measurable indices rather than relying on damage assessments. This approach offers several advantages, including lower transaction and administrative costs, resulting in lower premiums. Parametric insurance also minimizes moral hazard and adverse selection concerns and enables quick resolution of claims and pay-outs. However, it does involve a potential drawback known as basis risk, where the chosen index might not perfectly align with the actual losses incurred.

In the context of seismic risks, the modelled losses estimated in the Hyperion project can provide a suitable index for parametric insurance. By using these estimates, the financial risk management strategy can be tailored to specific seismic risk dynamics and facilitate a rapid and efficient response in case of disasters.

To optimize these financing options, we employ a comprehensive approach known as risk layering, which categorizes risks based on their return periods or probabilities. Risk layering facilitates the strategic deployment of various financial tools for each risk layer, resulting in enhanced efficiency and reduced overall costs of risk financing.

We define three risk layers: (i) low-impact, high-frequency risks, where risk retention measures like contingency or mutual funds are most appropriate; (ii) medium-to-severe risks occurring at lower frequencies, for which risk transfer through parametric insurance is identified as the optimal financial risk management tool; and (iii) very high-impact, highly infrequent risks, requiring risk absorption through financial assistance from the public sector and international donors. We identify the optimal reserve fund amount and parametric insurance attachment point that minimize the overall costs of the strategy while maintaining a low probability of reserve shortfall. The total cost calculation takes into account various factors, including the opportunity cost associated with the reserve fund, the opportunity cost of the insurance premium, and the potential cost of borrowing in the event of a reserve shortfall.

Let us for example consider the two case studies on Rhodes and Granada studied in the HYPERION project. The seismic risks in these cities are evaluated based on a 10,000-year stochastic catalogue of yearly direct and indirect losses. Both direct and indirect losses are categorized and organized into distinct macro-sectors, providing a comprehensive understanding of the impact on various segments of the economy. The macro-sectors include residential, tourism (including food & beverage, arts & entertainment, and accommodation), and commercial (including retail stores, offices, real estate, technical activities, wholesale trade, retail trade, finance & insurance, trade & repair of vehicles, warehousing, and other services), as presented in the previous sections.

For each city and each macro-sector, we design a risk-layering financial risk management strategy by finding the optimal reserve fund amount/insurance attachment point that minimizes the total cost via a 10,000 year Monte Carlo simulation. The opportunity cost and borrowing cost are estimated using the long-term interest rate and the bank interest rates on loans for each Country, respectively (ECB).

Results show how financial tools can help manage financial risk related to natural disasters and offer flexible and tailored strategies to efficiently mobilize resources when needed and minimize the long-term costs. The take-home message is that a good integrated strategy needs to take into account all factors, and work in synergy with other risk management mechanisms.

2.7 Guidelines and techniques

Five Business Continuity Strategies (BCSs) are proposed that aim to enable the critical processes of Cultural Heritage (CH) communities to continue operating at least to the minimum needed extent, when those are exposed to Climate Change (CC) or non-CC aggravated hazards severely impacting their critical infrastructure and/or supply chains. Initially, a brief literature review is undertaken on state-of-the-art aspects that are relevant to business resilience as well as to key Business Continuity Plan (BCP) elements. Thereafter, a detailed description of each of the considered BCS is given, along with the relevant advantages and limitations. The first BCS (BCS1), namely the “do-nothing” strategy, corresponds to the absence of comprehensive risk mitigation planning and is used herein as a benchmark for assessing the performance of the other four strategies. The second BCS (BCS2) involves “reciprocal agreements”, which are deemed to be mutual actions signed between local businesses of similar size that operate within the same sectors to allow for a resilience load balancing. Suitable for service-based businesses, the third BCS (BCS3) is related to a “work-from-home” framework and essentially involves the orientation of several employees to work from their own premises. On the other hand, the fourth BCS (BCS4), namely “business traffic redistribution” strategy, is more suitable for large organizations operating on a series of interchangeable physical assets, which can satisfy increased demand requests if needed. The fifth BCS (BCS5) is the insurance, a strategy that is always recommended for risk mitigation as it can reduce both the indirect and the direct losses of a disaster. Two insurance approaches have been proposed in the previous section, these being the “traditional indemnity” and the “innovative parametric” insurance. We have developed several methods to integrate the aforementioned BCSs in the context of the socioeconomic tool of the HYPERION platform.

Each BC strategy requires a certain degree of involvement by the municipal authorities or the individual firms operating within the CH area so as to enhance the redundancy of the local economy to facility and lifeline disruptions. Thus, depending on the local socioeconomic characteristics and the mitigation strategy of the considered urban region, one BC strategy might be more favorable than others. To demonstrate the impact of the BCS on the recovery process of an economy following the occurrence of a hazard event, a socioeconomic framework was developed in HYPERION. This framework is founded on the Adaptive Regional Input-Output (ARIO) model that was initially proposed by Hallegatte[13] for simulating failure propagations due to supply and demand outages. The model is built upon a business taxonomy approach, which involves the aggregation of the individual businesses that operate on a local community to distinct business sectors. The importance of each business sector to the local economy is reflected by its annual GVA, whose distribution over the year is nonuniform for businesses operating in the tourism industry, in which case it experiences a peak during the high season.

Through this process, we have shown the effect of each BCS to the production capacity of a business sector by realizing several hypothetical disaster scenarios in two HYPERION pilot sites, i.e., the city of Rhodes and the city of Tønsberg. Based on the estimated indirect losses that are predicted for these scenarios per pilot site by means of the socioeconomic analyses, a number of general yet informed guidelines are given for the application of the BCSs on either product- or service-based business sectors.

Namely, as the city of Rhodes is a popular tourism destination, the “Accommodation” (hotels, BnBs, etc.) and “Food and beverage” (restaurants, bars, etc.) sectors reflect a large percentage of the city’s overall annual GVA. On the other hand, sectors such as “Manufacturing” or “Agriculture” are less important in terms of annual GVA, which indicates that Rhodes relies on external vendors for essential supplies, mainly via marine transportation.

On the other hand, in Tønsberg, “Retail trade” comprises the most critical business sector (i.e., the one with the highest GVA), since Tønsberg is traditionally defined as a trading town and a regional center where thousands of visitors come for shopping. However, given that most visitors only come for day trips and have their own holiday premises nearby, Tønsberg is not considered being a holiday destination such as the city of Rhodes, in which case tourists spend more time and hence should stay in hotels. As a result, there is a limited number of hotels and overnight stays in Tønsberg, a condition that is also reflected in the relatively low annual GVA of the “Accommodation” sector. On the other hand, the “Technical/scientific” and “Business services” sectors occupy a large percentage of the city’s annual GVA, since Tønsberg hosts several firms related to Information and Technology (IT) and communication e.g., cloud services, cloud storage, IT consultant, e-commerce services, web design.

Using the aforementioned approach, we may show that, in the case of a disaster scenario occurring in the city of Rhodes, assuming that a peril results in damages to the “Accommodation” business sector, forcing the 50% of hotels to shut down,

- BSC1 results in a total of 50 days is needed for the damaged hotels to fully recover. However, from the 35% disrupted retail stores, the 10% will be able to repair the damages after 2 months. On the other hand, the remaining 25%

[13] Hallegatte S. (2008). An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina, Risk Analysis, 28(3), 779-799. https://doi.org/10.1111/j.1539-6924.2008.01046.x

will have to seek for external funds to repair their facilities, a procedure that extends the restoration time to 6 months.

- BCS2 with intra-community reciprocal agreements would result in non-disrupted hotels accommodating a limited number of tourists, by increasing their production capacities only by 10%. The time for recovery is not significantly affected.
- BCS2 with intra-municipality reciprocal agreements would result in a percentage of the city's GVA related to the accommodation sector to be transferred to the nearby villages. More than 90% accommodation recovery would thus come in 25 days, and the total losses in GVA would be smaller.
- BCS5 with traditional insurance policy, would need a total of 3 months for the damage assessment and rehabilitation procedures to restore sector's productivity to 100%.
- BCS5 with parametric insurance policy (assuming that no negative basis risk was reported, payout started immediately after the event and repair works were initiated after 20 days) would need a total of 2 months for the "Retail trade" sector to restore sector's productivity to 100%.

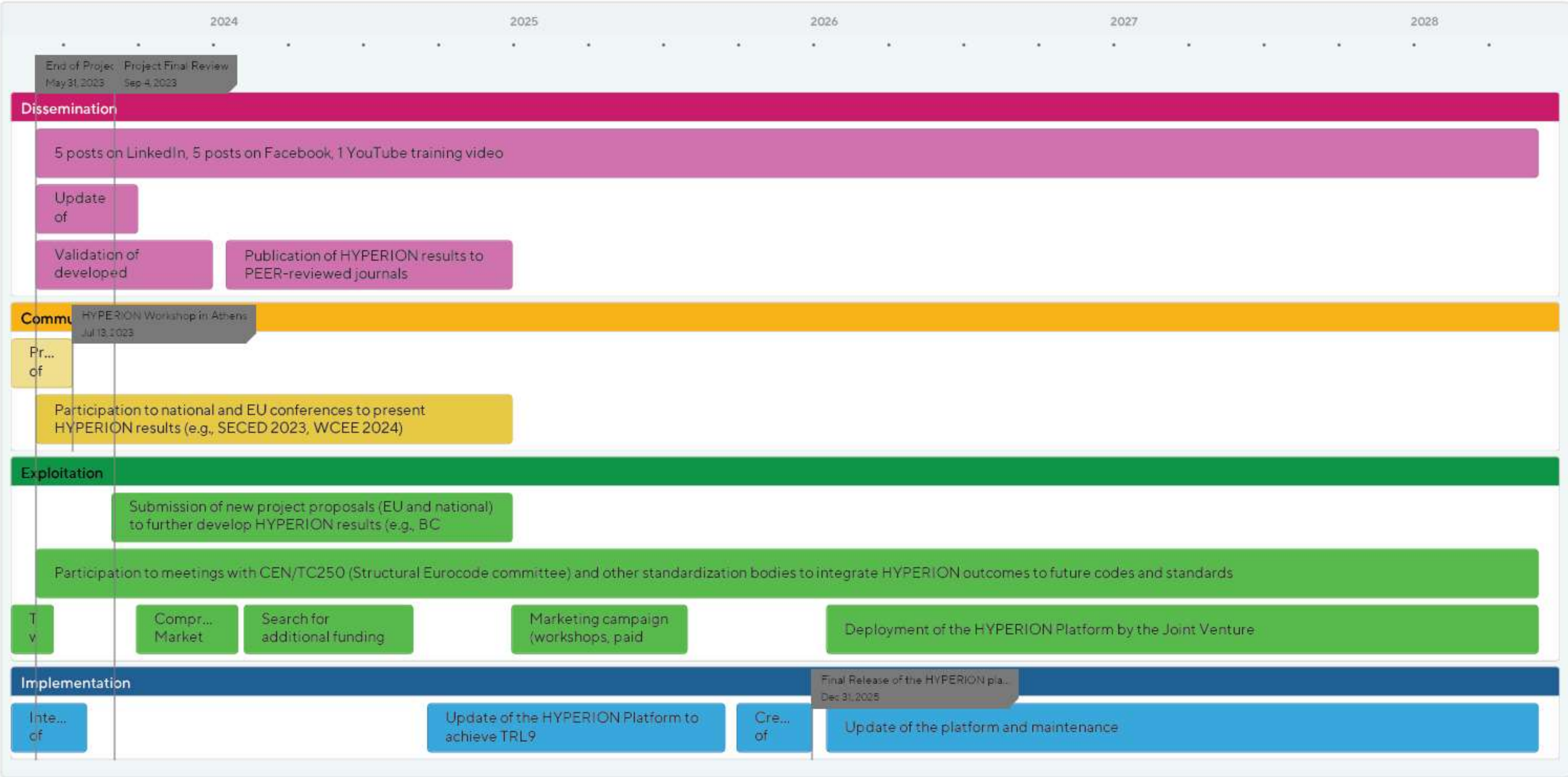
The second scenario, focusing on the city of Tønsberg, assumes the occurrence of a catastrophic event that results in a 40% reduction of the industry's production capacity, and a total of 4 months as the repair time needed for the damages to be fully restored. Other BCSs would have the following results.

- In case that no damage mitigation planning is adopted (i.e., BCS1) the hypothetical disaster scenario resulted in sector and community indirect losses that are equal to 15014.5 and 62901.1 thousand euros, respectively. Evidently, the functionality of several business sectors such as "Telecommunication and ICT", "Process Industry", or "Technical / Scientific" was affected by the disruptions in the "Business services" sector.
- BCS3 with 40% of the companies being able to shift to work-from-home, would result in the estimated sector and community indirect losses to be 9008.7 and 37740.7 thousand euros, respectively. Clearly, BCS3 can effectively mitigate severe economic impacts of important service-based firms, assuming that pro-active measurements have been taken to secure data integrity and rapid personnel adaptation.
- When 70% of the businesses adopted BCS3, the sector and community indirect losses were estimated being equal to 4632.4 and 19223.4 thousand euros, respectively.
- If BCS4 with 25% redistribution capacity is adopted, we assume that each company transfers its manufacturing machinery and equipment from the disrupted assets to the non-disrupted ones (e.g., by rearranging old facilities used for stocking purposes). In this case, the estimated sector and community loses were reduced to 5518.3 and 14813.8 thousand euros, respectively.

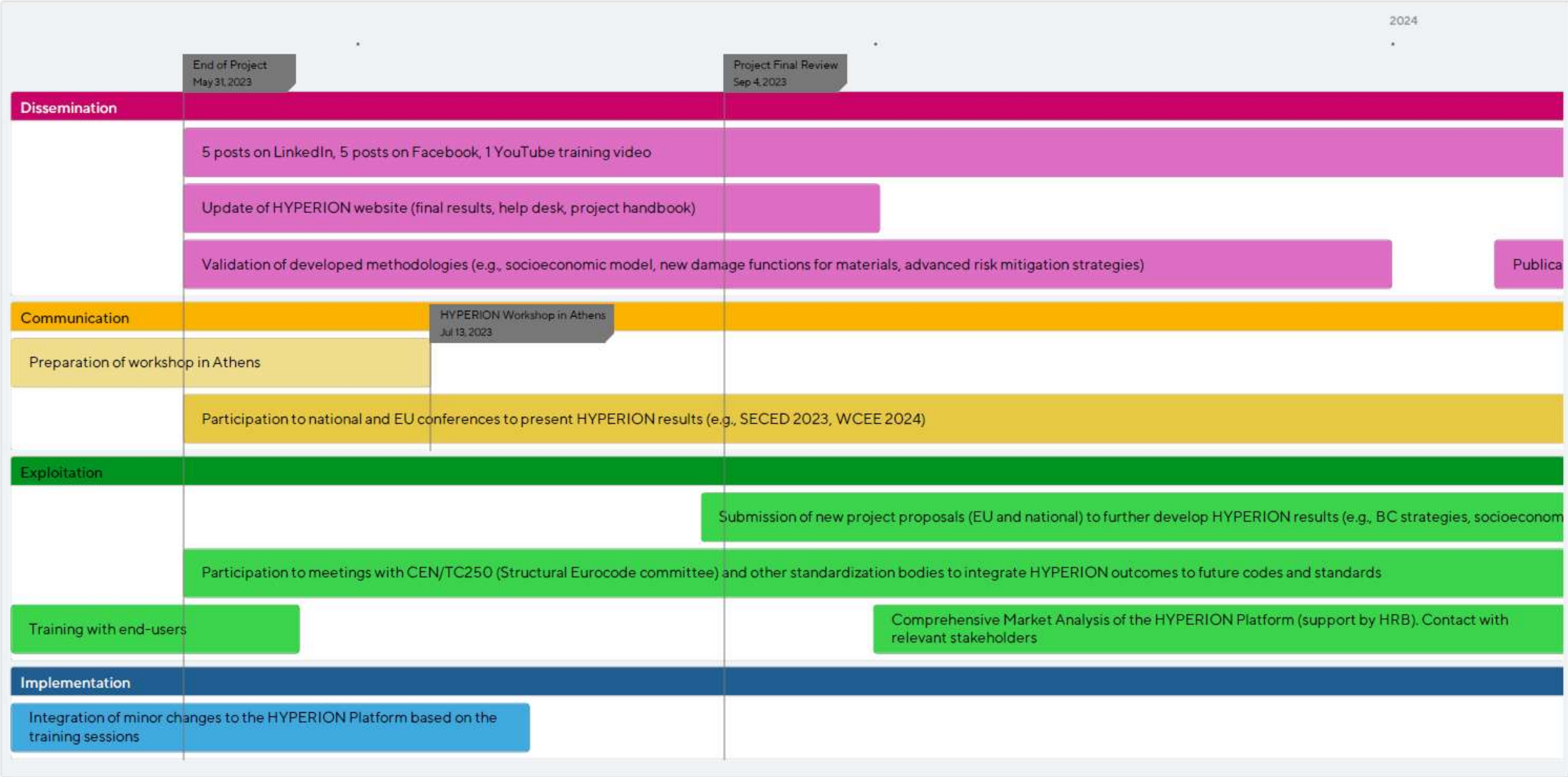
3. HYPERION Roadmap

Based upon the results of the HYPERION project, and the interest expressed by stakeholders during the various training and demonstration session that were conducted, the consortium is expressing its commitment to further develop and enhance the outcomes of the project, through a roadmap that is outlined in the following figures:

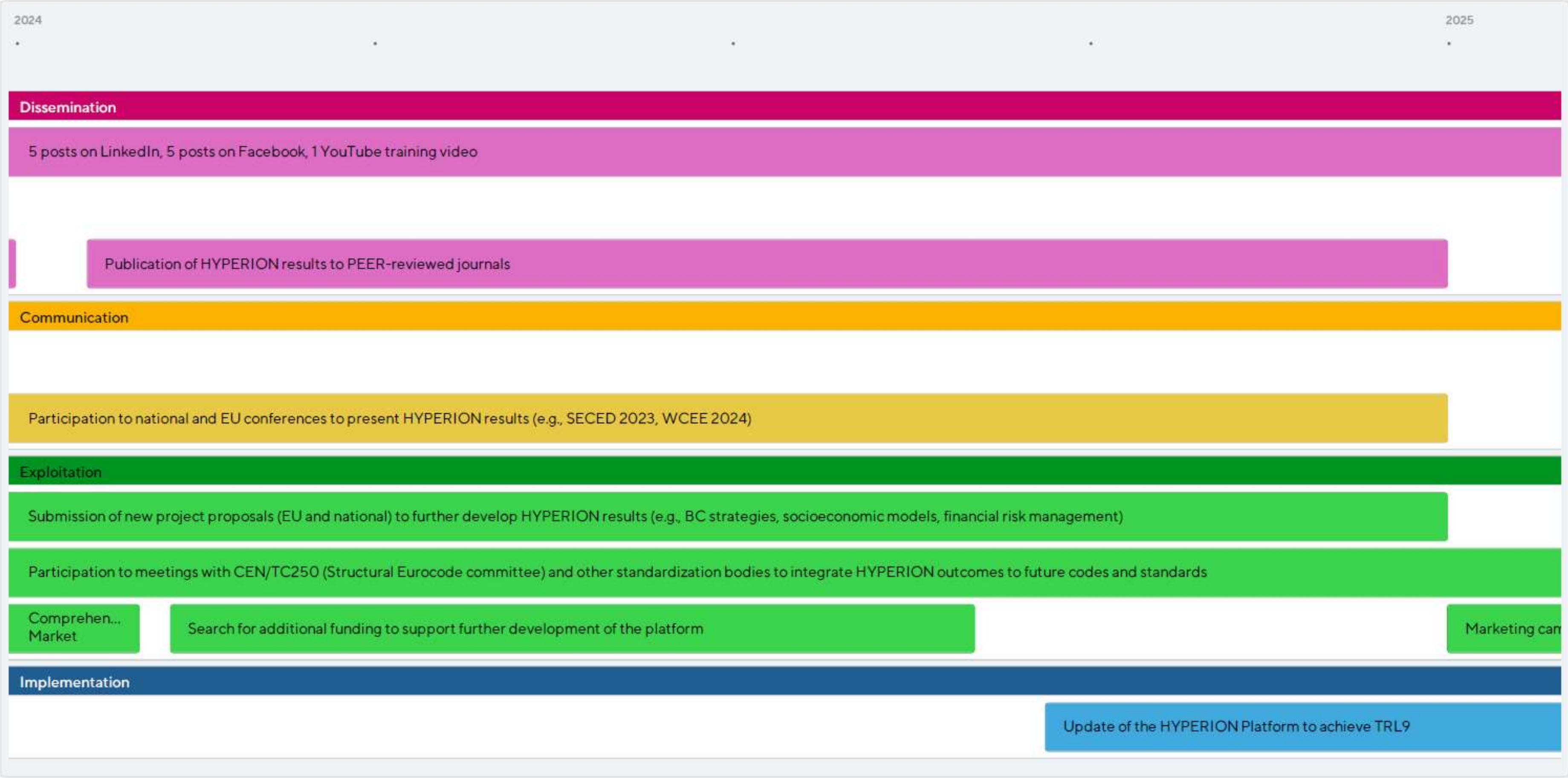
HYPERION Roadmap 06/2023-06/2028



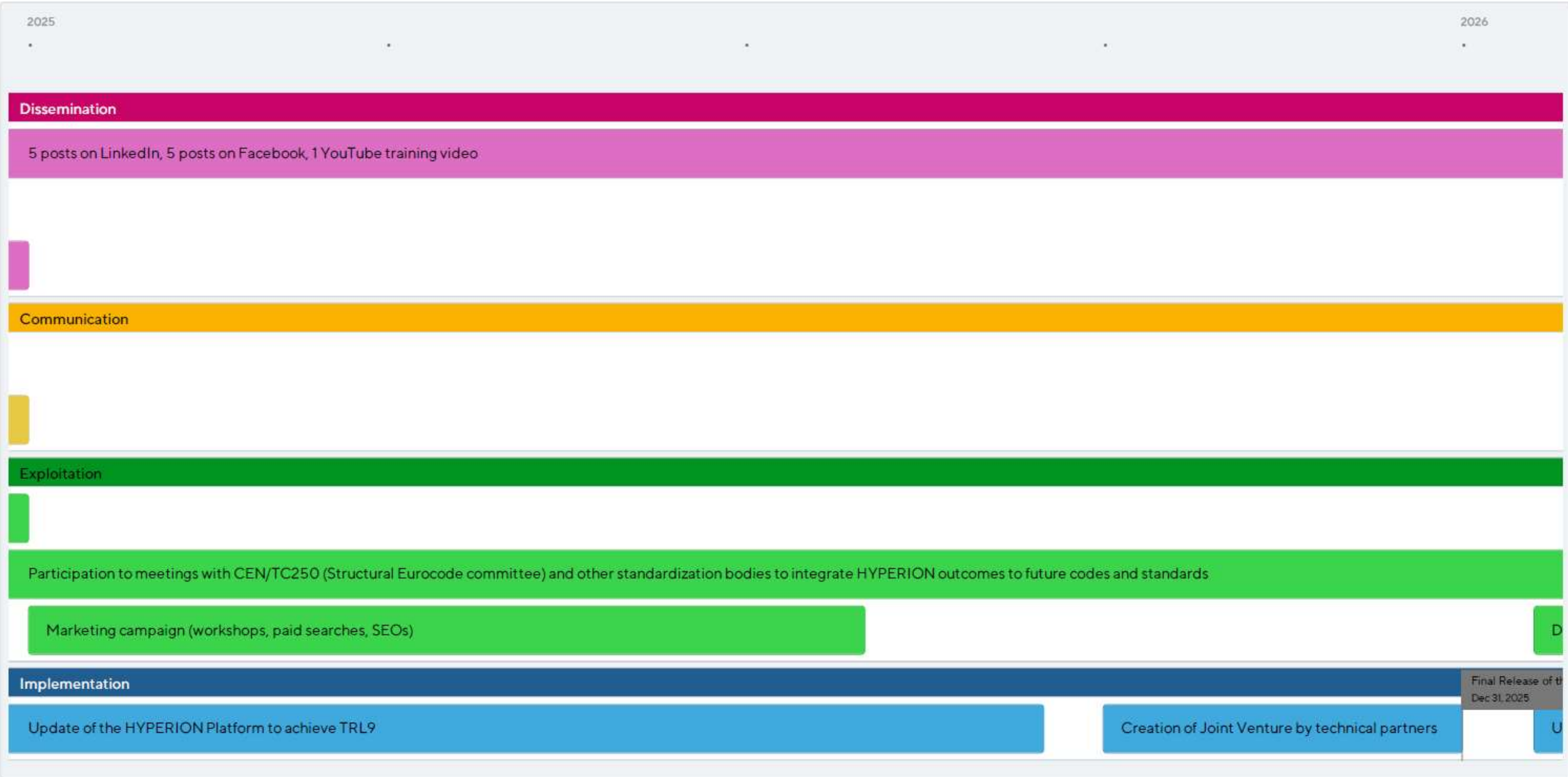
HYPERION Roadmap 2023

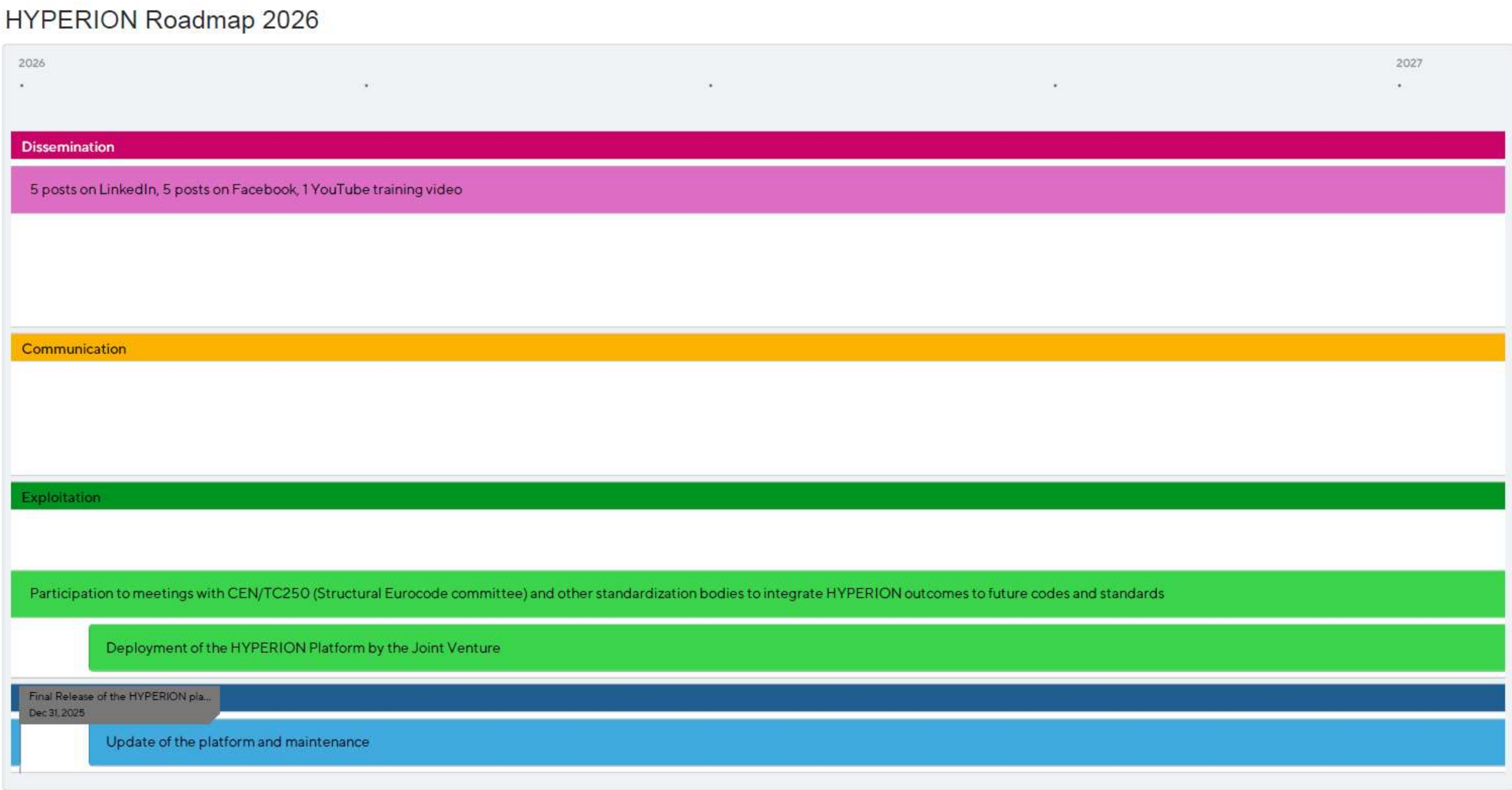


HYPERION Roadmap 2024

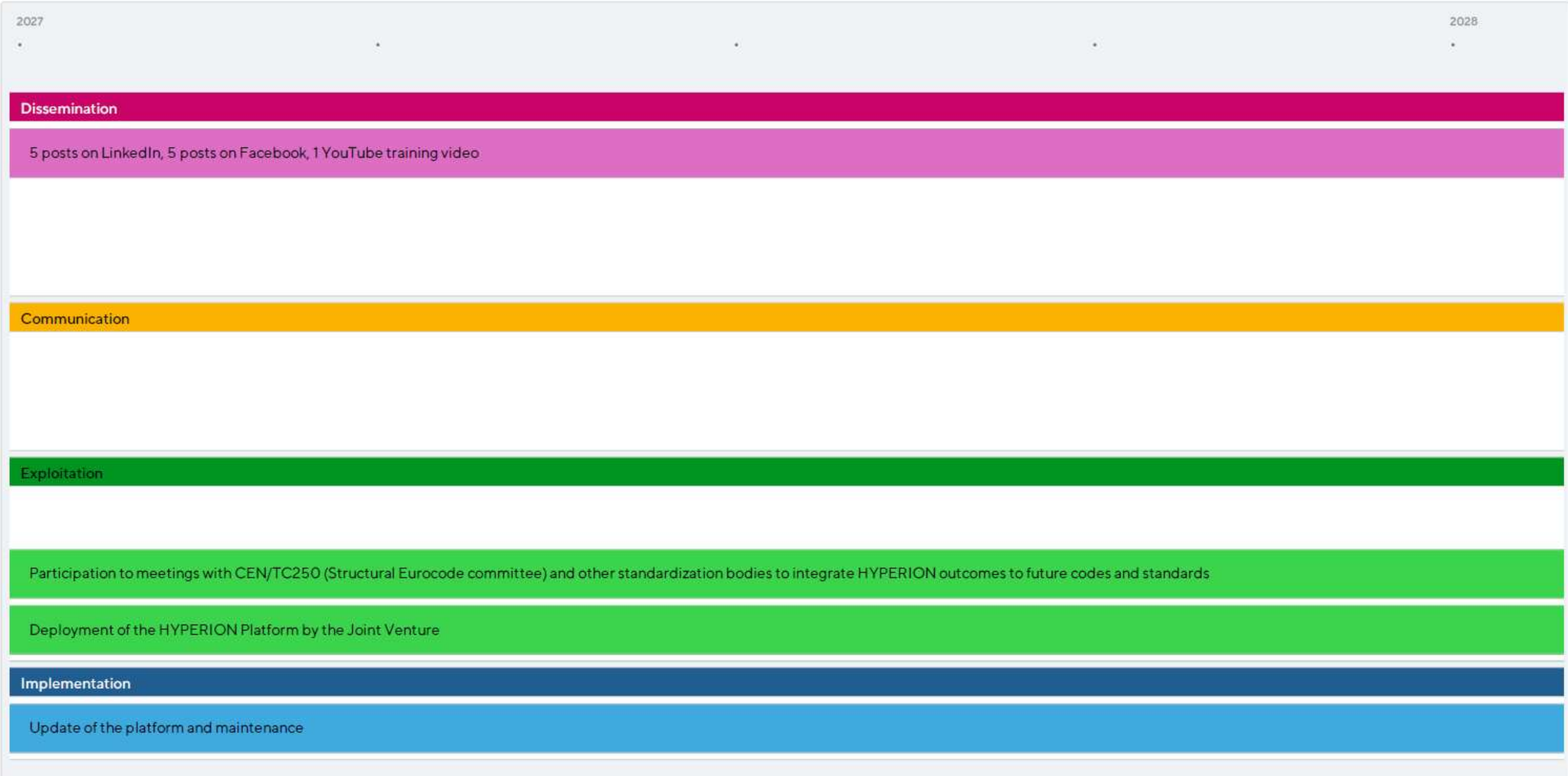


HYPERION Roadmap 2025

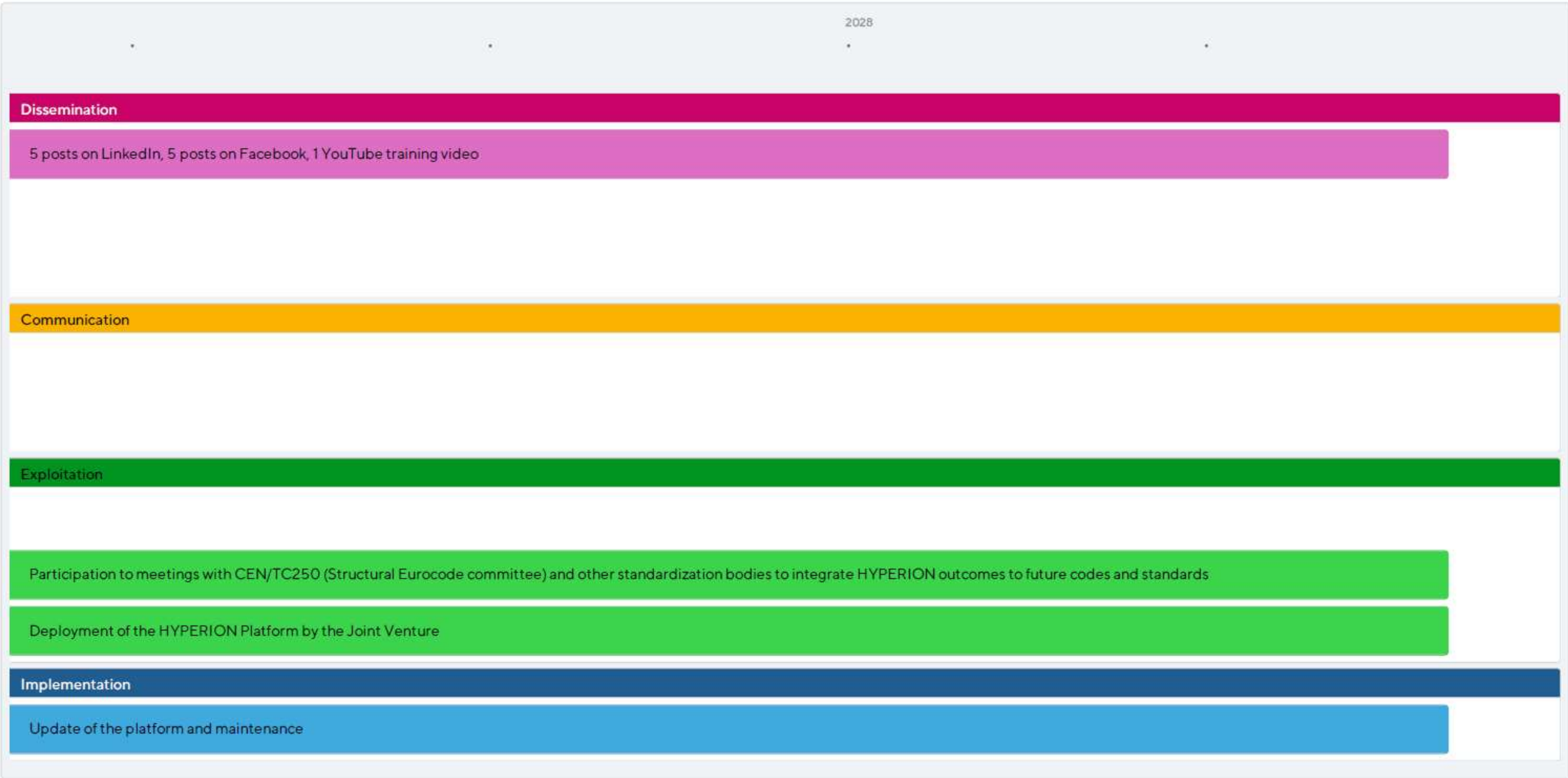



HYPERION Roadmap 2026
2026
2027
Dissemination
5 posts on LinkedIn, 5 posts on Facebook, 1 YouTube training video
Communication
Exploitation
Participation to meetings with CEN/TC250 (Structural Eurocode committee) and other standardization bodies to integrate HYPERION outcomes to future codes and standards
Deployment of the HYPERION Platform by the Joint Venture
Final Release of the HYPERION pla...
Dec 31, 2025
Update of the platform and maintenance

HYPERION Roadmap 2027



HYPERION Roadmap 2028



Namely, we are planning to take up the following actions that will promote the results of the project, with the aim of reaching a technology readiness level of TRL9 in the following 5 years, either through partners' own funds, private investors, of through EU grants.

1. **Steps towards market uptake**

The project has developed several exploitation strategies to foster market introduction of the key project innovations within the wider European community of Cultural Heritage sites operators, city managers, and other relevant interested parties. It has also organized an Exploitation workshop during its Final Event to evaluate these strategies with a group of stakeholders from various fields and sectors.

HYPERION's technologies are very promising and we believe that the market will be highly interested in adopting and exploiting its results and tools. The consortium has identified a total of eight Key Exploitable Results (KERs) that possess high degree of innovation, exploitability, and impact (see Deliverable 10.5). Consequently, comprehensive exploitation strategies and business plans have been delineated for the following four KERs: (i) the Mobile App, (ii) the HRAP, (iii) the Middleware, and (iv) the HYPERION Integrated Solution. Detailed Market Analysis has showcased that these KERs possess compelling exploitation potential, as they belong to cutting-edge industries (e.g., IoT, social media, PSIM) that are expected to grow significantly in the following years. Moreover, the KERs demonstrate distinct capabilities and advantages with respect to other competitive solutions and, thus, can achieve high market penetration.

For each KER (i) to (iv), an exploitation roadmap has been derived that describes all the technical, dissemination & communication, and business activities that should be implemented by the consortium to deploy the KERs to their respective market. Special heed was given to construct the exploitation roadmap of KER (iv), which is the final outcome of the project and integrates all the results produced by the individual partners. In particular, the consortium envisions deploying the KER by the end of 2025, i.e., 2.5 years after the official end of HYPERION. The first months will be spent conducting further market analysis (potentially with the guidance of HRB services), engage with relevant stakeholders, and search for additional funding.

Given that sufficient sources are available to commercialize KER (iv), the technical partners will proceed with implementing all the technical activities needed to increase its TRL from 6 to 9. Such actions include demonstrating the actual system prototype in an operational environment, enhancing the user interface of the platform, expanding the hazard set to include more perils (e.g., storms, droughts), and validating the socioeconomic engine with data from actual disasters. Moreover, a series of dissemination & communication activities (e.g., workshops, publications, marketing campaign) are foreseen to facilitate the introduction of HYPERION to the market of CH and civil protection. Finally, the roadmap comprises several business-related actions needed for KER's commercialization, including the formation of a Joint Venture by RISA, CYRIC, and ICCS and licensing of results to the venture.

2. Dissemination actions

In the following 5 years, consortium members are planning to continue disseminating the results of the HYPERION project through a number of activities that can be grouped into the following activities:

- Maintenance and support of the HYPERION website. The webpage will be a platform for dynamically changing interactions, debates, and opinion;
- Social media presence (LinkedIn, Facebook)
- Mass Media Presence (for example, TV program in Canal Sur (south of Spain), on the HYPERION project, https://www.canalsurmas.es/videos/77955-conciencia-i-semestre-2023-18062023/)
- All the materials and publications will be open access;
- Release unpublished scientific work
  - 18th World Conference on Earthquake Engineering, July 2024, Milan
  - SECED2023: Earthquake Engineering & Dynamics for a Sustainable Future
  - Other relevant conferences and journals
- Following the closure of this project, the HYPERION's partners involved are dedicated to run HYPERIONApp;
- HYPERION's Research community will keep active all repositories of produced Publications (Papers, Books) Posters, Presentations, Data, Software, etc during the project's lifetime and further research activities and publications containing new insightful results will also be included;

3. Training and Support

One of the key actions for the uptake of the HYPERION results is to maintain and expand the crowd of involved and interested stakeholders. Based on the results of our workshops and training sessions during the last period of the project, we have seen that the HYPERION platform is best received when its key features are shown in practice. We have therefore planned for further actions to approach stakeholders through,

- Focused presentations to CH stakeholders, especially municipal and governmental personnel
- Prepare a set of roadshow presentations per HYPERION component for rapid dissemination of Hyperion results in adhoc meetings

4. Policy Making

Partners are planning to participate in EU Technical Committees and clustering activities in order to influence policy making towards the uptake of tools and methodologies relevant to the HYPETION outputs. This effort will be coordinated by the project's technical coordinator, Prof. Dimitrios Vamvatsikos, who is a full member of Eurocode committees (e.g., CEN/TC250, "Structural Eurocodes").

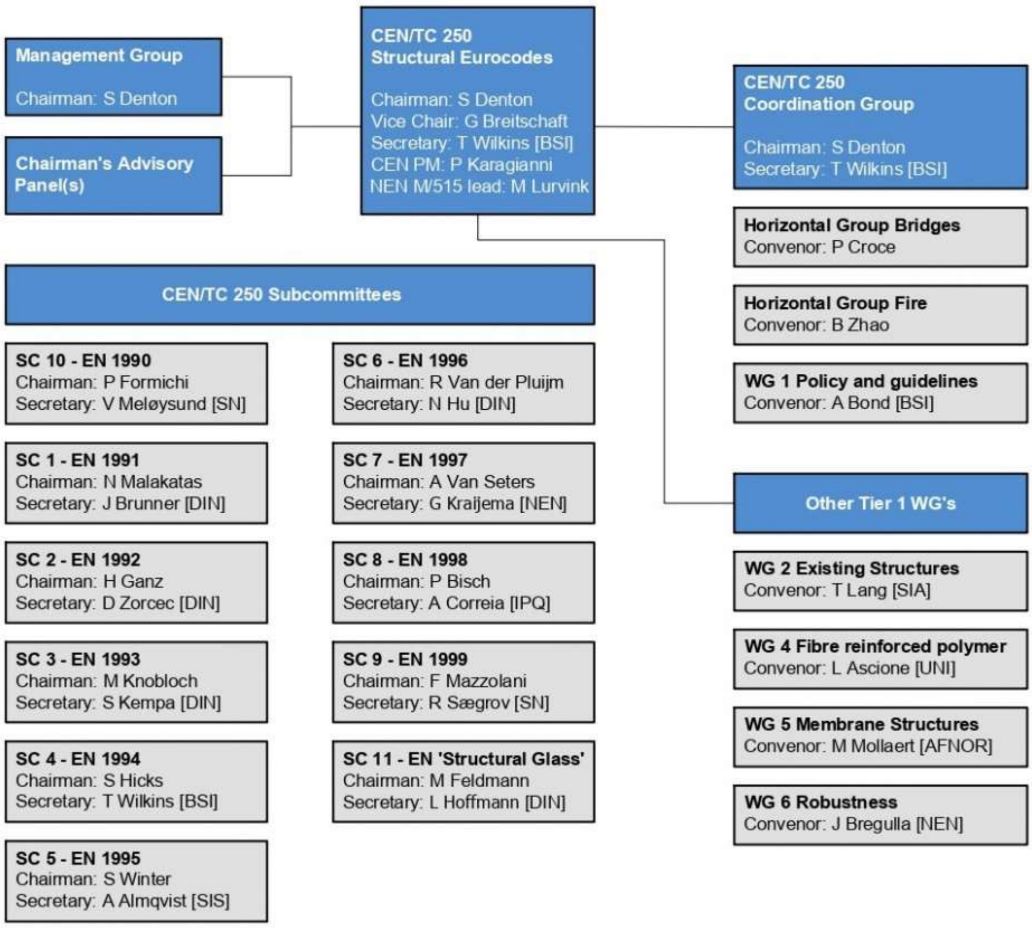


Figure 41: CEN/TC250 organigram

4. Conclusions

The HYPERION project started in June 2019, and marked the strong concern of the European Commission on preserving Cultural Heritage in times of Climate Change (CC). Looking back, we acknowledge that it has been a rough but rewarding journey. The project itself had been quite ambitious, aiming to create a strong safety net for supporting both Cultural Heritage structures, and the surrounding communities. In summary, HYPERION achieved its goals through the following:

- Developed a wide range of innovative methodologies which assess the effect of a multitude of CC or human inflicted threats on the landmarks themselves,
- Developed community engagement tools that amplify community involvement both proactively and reactively to major disrupting events, and business continuity plans to strengthen community responsiveness.
- Integrated all these tools and methodologies into a single decision support tool that gives stakeholder a full situational overview and trains them to the effects of unforeseen events.

During the past years, we were able to develop, deploy and test all these different subsystems of the project, and we are now in the position to claim that the entire integrated system is in place.

In this deliverable we showed how the HYPERION system can be used to provide assistance to stakeholders and facilitate them in their effort to alleviate the effect of CC and natural hazards, so that they can make not only CH sites, but their whole communities more resilient in a climate-change era. For this purpose, the document has reported examples of how to use HYPERION technology to acquire

- technical information on sustainable reconstruction of historic areas,
- proper adaptive response strategies for CC and other hazards scenarios,
- post-disaster reconstruction example,
- practical checklists and references to assist practitioners, field-workers, cities and cultural authorities, etc. in better decision making,
- recovery requirements for various sectors,
- information on financial tools to mitigate risk, including a novel set of CH-area-specific parametric insurance plans, designed to cover expected degrees of extreme CC and non-CC event severity
- guidelines and techniques to encourage, facilitate, and develop bespoke reciprocal agreements between same type of businesses for timely service recovery.

Having developed a strong belief in the project outcomes, we also provide a roadmap for wider communities’ and other stakeholders’ engagement in the following 5-year period, including several strategies to foster the adoption of the key project innovations within the wider European community of Cultural Heritage sites operators, city managers, and other relevant interested parties.