D5.4 HRAP software and documentation

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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

CC	Climate Change
CH	Cultural Heritage
DS	Damage State
FEM	Finite Element Model
GMF	Ground Motion Field
HRAP	Holistic Risk Assessment Platform
IM	Intensity Measure
MHVM	Multi-Hazard Vulnerability Module
SES	Stochastic Event Set
SG	Structural - Geotechnical
WP	Work Package

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Executive Summary

HYPERION aims to utilize different tools and services aiming to provide an advanced simulation environment named Holistic Risk Assessment Platform (HRAP). HRAP can be used for assessing the risk and resilience of historic areas of cultural heritage (CH) as well as potential impacts due to various hazards such as earthquakes and weather-related hazards and it also supports the identification of cost-efficient adaptation measures.

The integrated release of HRAP (type OTHER) includes both long-term and short-term impact assessment tools. The HRAP software engine allows the integration of various risk and impact analysis models defined in WP4 and WP5 by "chaining" them appropriately in scientific workflows. The goal is to provide an end-to-end simulation environment enabling the user to run different pre-event "what-if" scenarios and post-event "what-is" assessments to offer decision support both before an event occurs and after it has.

The HRAP platform combined with the analytical tools produced in WP4 and WP5 is an innovative modular and expandable software for Consequence-Based Risk Assessment allowing both the development of risk reduction strategies and the implementation of mitigation actions to minimize the impact of natural hazard on CH sites, identify the most vulnerable elements, and provide cost-efficient adaptation measures.

1   Introduction

1.1   Purpose of the Document

The document is a part of Work Package 5 (WP5), regarding the HRAP integrated environment. HRAP is a platform for Holistic Risk Assessment that is able to integrate diverse risk assessment analysis tools and provides an environment for "what-if" and "what-is" analyses.

The work package structure of HYPERION and especially the WP5 is based on the the fact that risk model development and software development are implemented in two different stages. Therefore, in HYPERION the scientists and engineers develop the risk model (inputs, outputs, calibration, validation) and software developers work closely with this team to build efficient and user-friendly tools that provide a simulation environment to run end-to-end impact/resilience assessment scenarios for the test cases of CH sites. In this respect the HRAP has been developed as an extensible platform that is able to accommodate different types of datasets (e.g. hazard, assets, interconnections, fragilities), file formats, and risk analysis algorithms and provide suitable user interface elements for scenario and data repository management, analysis workflows setup, and intuitive result visualisation and reporting. In the context of the WP5, advanced models for the natural hazards are developed as well as the Structural – Geotechnical (SG) tool, the Multi-Hazard Vulnerability Module (MHVM), and the socioeconomic impact assessment tool; HRAP is designed to integrate and chain all these tools together. An overview of the WPs and their interconnections is illustrated in Figure 1.

The outcome of WP5 is transferred to WP7 and WP8 to become a part of the final version of the HRAP platform that will provide the simulated data that paired with the integrated monitoring system of HYPERION will feed the Decision Support System.

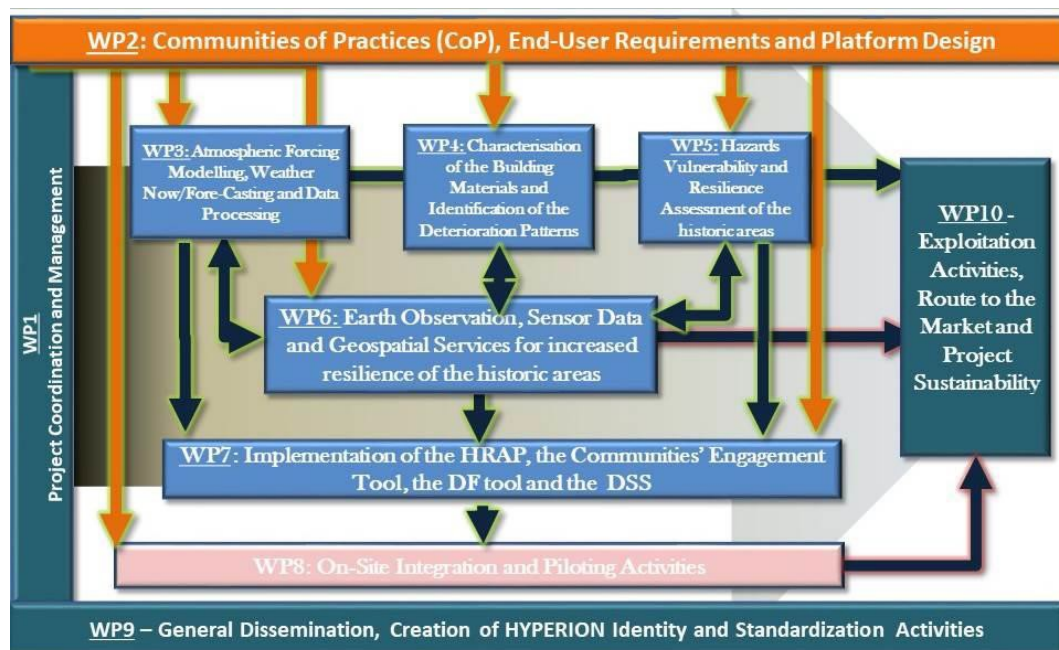*Figure 1: HYPERION project structure showing WPs and the interconnections*

1.2 Structure of the deliverable

The document is broken down into four chapters.

Chapter 1 is the introduction.

Chapter 2 provides an overview of the Holistic Risk Assessment Platform of HYPERION.

Chapter 3 presents the short-term impact assessment tool.

Chapter 4 presents the long-term impact assessment tool.

Chapter 5 presents the conclusions.

2   HRAP Conceptual Framework

2.1   Framework Structure

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 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. Also, the framework is implemented in open-source code-base using Python to be fully linkable with the MHVM. Thus, HRAP is directly engaged at all HYPERION phases using pre-computed results to assess the consequences of natural hazard events for the four case studies.

The pre-event operation framework developed for HYPERION is presented in Figure 2. 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 3. In this phase the results from a private sensor network is 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 (Figure 4). 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.
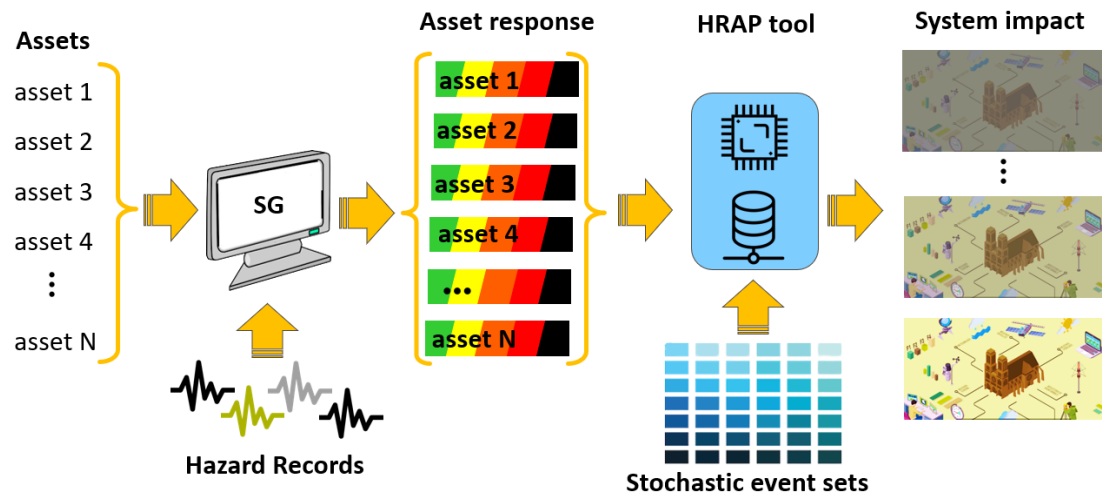

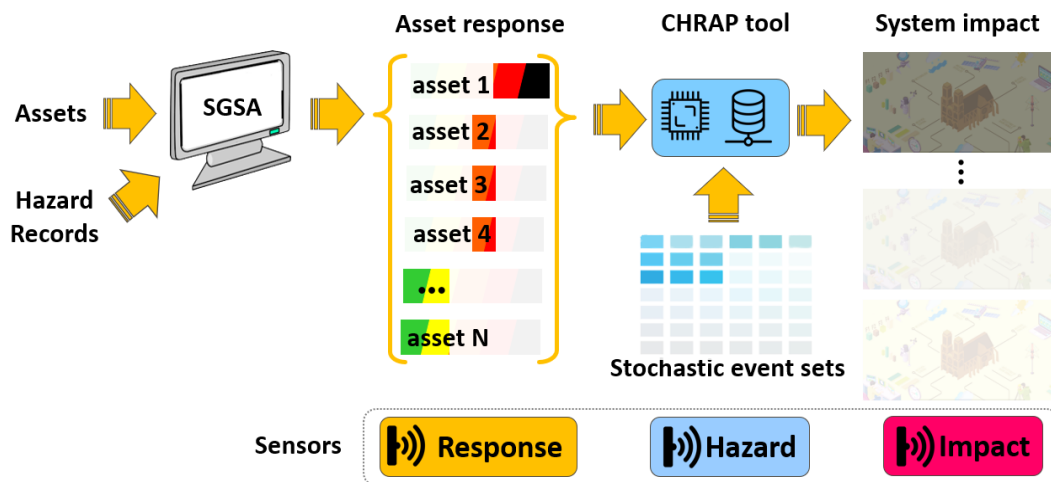*Figure 2: HYPERION pre-event operation mode. All scenarios are still plausible.*

Figure 3: 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.

Figure 4: Test setup for Ambient Vibration Testing: the accelerometer and the data logger are identified in blue and yellow circles, respectively

2.2 Assets at risk

The main assets integrated in HRAP are: (a) Tier 1–2 structures modeled in detail, (b) Tier 3 "portfolio" assets modeled in aggregate and (c) interconnected non-CH assets (e.g. the water supply network of Rhodes). The primal assets at risk in HYPERION are the Tier 1-2 CH buildings for which high quality component-by-component models used for a detailed vulnerability assessment. The portfolio assets are modeled via literature fragility and vulnerability functions that provide fast results to ensures near-real-time assessment of the entire city via the developed tools and the pre-calculated analyses. Network models are added including their connectivity and interactions. The hazards that are applied to each asset are determined based on their vulnerability towards it. The hazards considered are geo-hazards (e.g. seismic ground acceleration) and climate/weather-related forcings (rain, wind, etc.) that also include the impact from Climate Change (CC) through climate models (EUROCORDEX, Jacob et al. 2018).
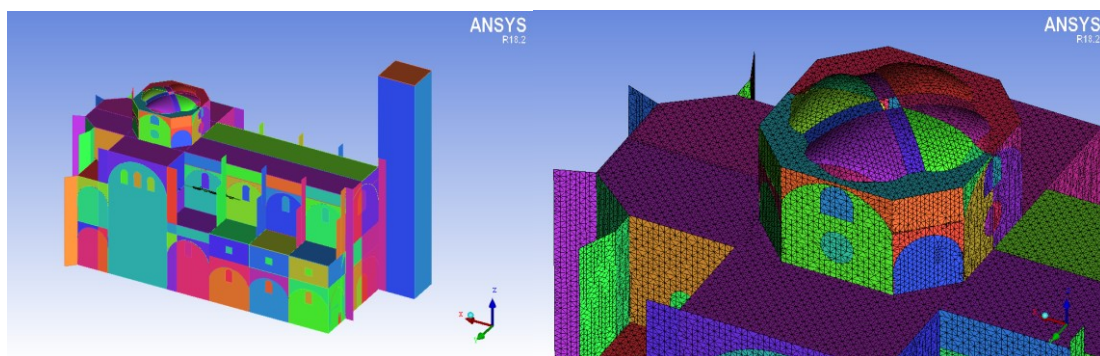

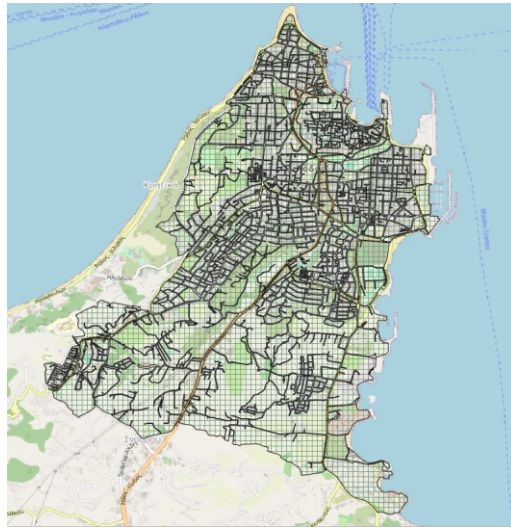*Figure 5: Structural FEM model of San Jerónimo Monastery*

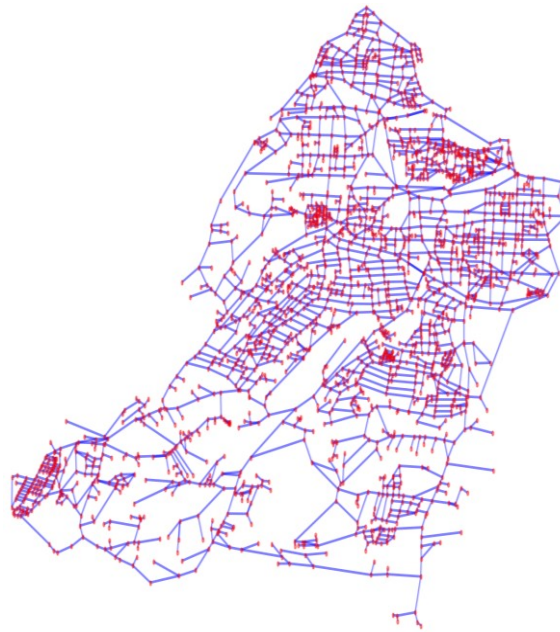*Figure 6: Portfolio assets divided in blocks for Rhodes*

Figure 7: Water supply network for Rhodes

3   HRAP Short-term Impact Assessment Tool

The impact assessment tool of HYPERION is divided into the short-term and the long-term tools. 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) and are offered in hdf5/ csv format as can be displayed as shp/ tiff files.

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 in hdf5 or csv format. Any of those events can be selected, and their rupture location and the corresponding GMFs are returned and shown to the user (Figure 8). The consequences of the given event are determined for all critical assets as for instance shown in Figure 9 and Figure 10 where the bar charts show the distribution of buildings belonging to different damage states.
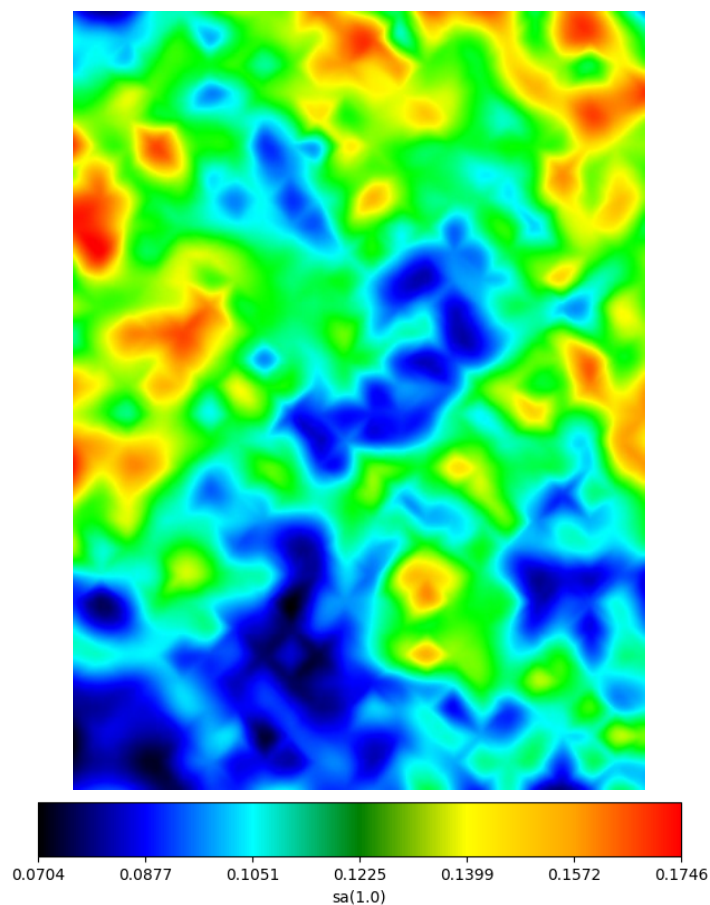

Figure 8: Ground motion field

(a)   (b)

Figure 9: (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.
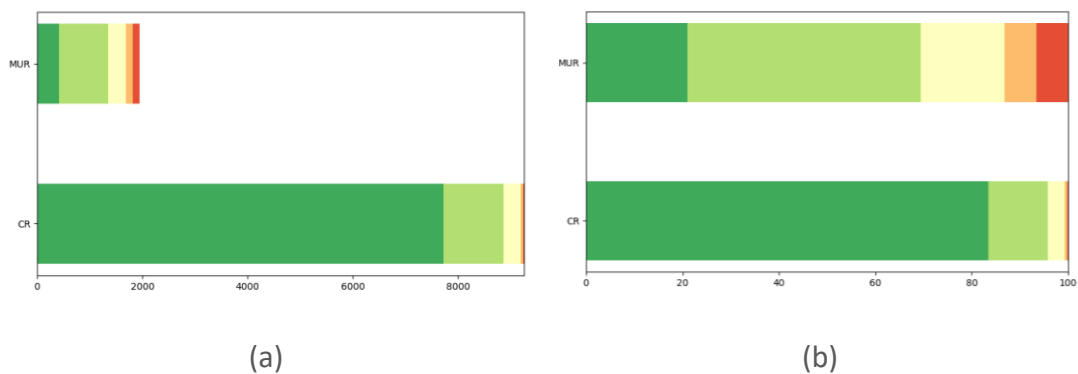

(a)   (b)

Figure 10: (a) Number of buildings per damage state and typology; (b) Percentage of buildings per damage state and typology.

4   HRAP Long-term Impact Assessment Tool

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 in png format for different damage states, for two of the cities, Granada and Rhodes (Figure 11). Additionally, the risk under CC is presented via graphs with appropriate risk indicators. The impact of climate change (CC) on the deterioration risk of building materials is given by considering data from different global climate models (EUROCORDEX). The most dangerous deterioration mechanisms for stone-based materials are frost damage and salt crystallization. Results for Venice and Granada case studies are shown in Figure 12 and Figure 13, respectively, as examples for one model and one part of the building for those mechanisms. The y-axis of the figures is the corresponding indicator and on x-axis there is the years for which the risk is calculated. The risk of frost damage uses as indicator the number of freeze-thaw cycles that occur during a year that may cause material fatigue and mechanical strength reduction. The risk of salt crystallization uses as indicator the number of dissolution-precipitation cycles that occur during a year, it

is calculated using the phase diagrams of the salts present in the walls of the analyzed buildings. The phase diagrams show the critical relative humidity values. Fluctuation around the critical relative humidity drives the cycle of dissolution (i.e., deliquescence) and precipitation (i.e., crystallisation). The main Cultural Heritage (CH) buildings analysed in Tønsberg are made of wood and therefore they are more sensitive to biological deterioration. For this reason, the outputs of the wood's deterioration mechanism are integrated into HRAP, without reporting them in the present deliverable.

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 14, Figure 15, Figure 16). 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.

When it comes to the weather-related hazard, the climatic projections of different EuroCordex scenarios are presented for the weather-related parameters of interest as e.g. temperature, precipitation etc. (Figure 17). For HYPERION, three alternative CC EUROCORDEX scenarios are adopted, each as determined by 6 to 7 different climate models (Figure 18).
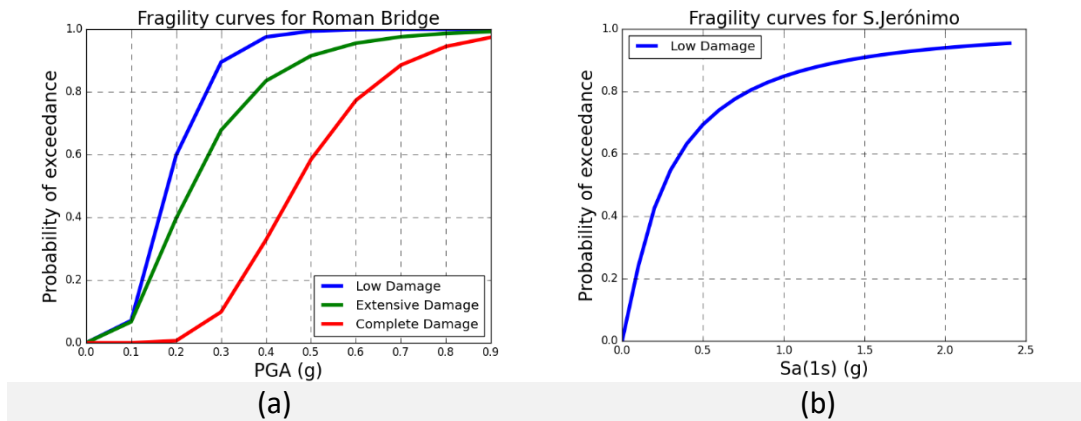
Figure 11: Fragility curves for (a)Roman Bridge (Rhodes, Greece), (b) Monastery of St Jeronimo (Granada,Spain)
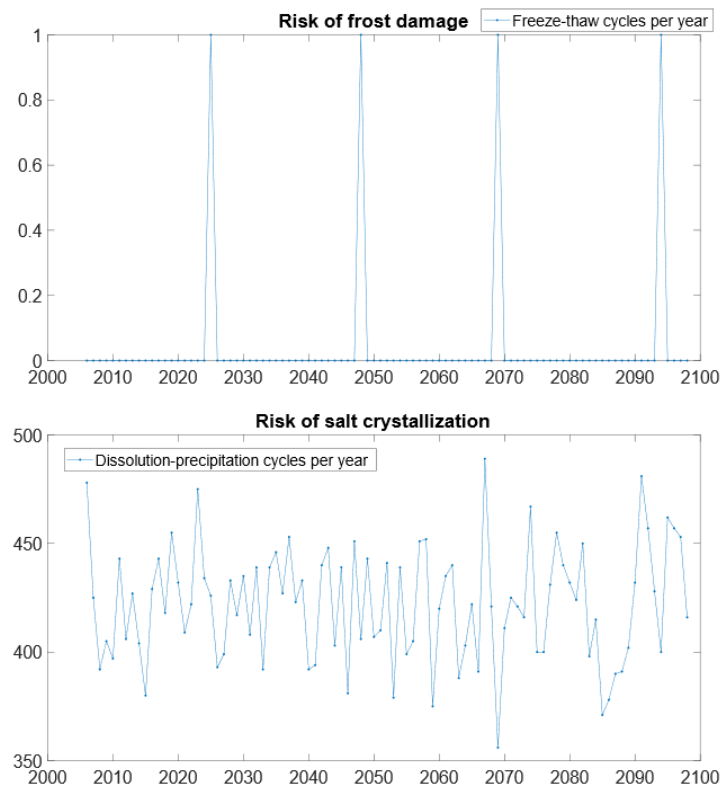
Figure 12: Examples of risk of frost damage and salt crystallization in Torre dell'Orologio, Venice (Italy over time for the RCP 4.5 scenario
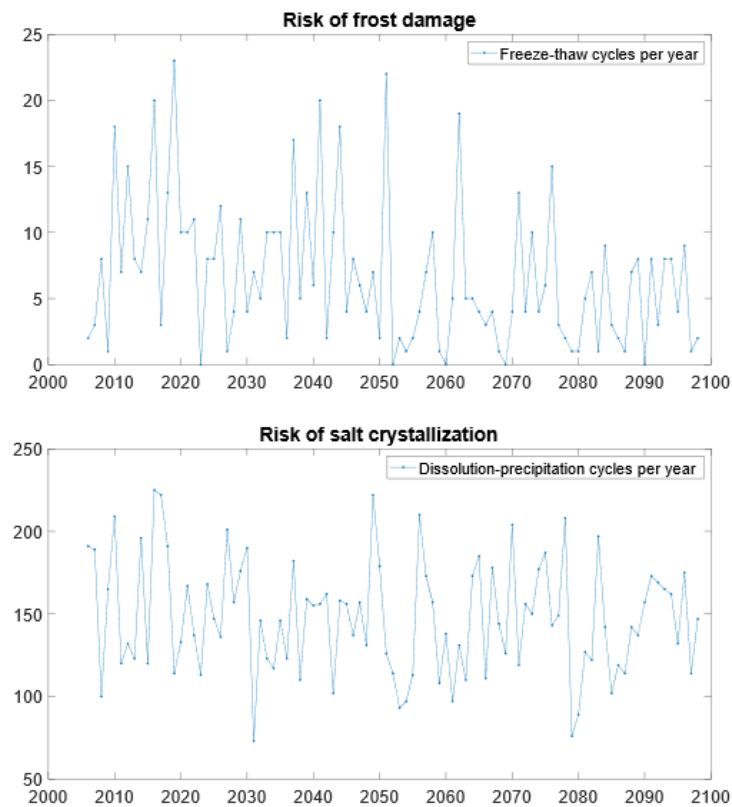
Figure 13: Examples of risk of frost damage and salt crystallization in the Monastery of St Jeronimo, Granada (Spain) over time for the RCP 4.5 scenario

(a)   (b)   (c)
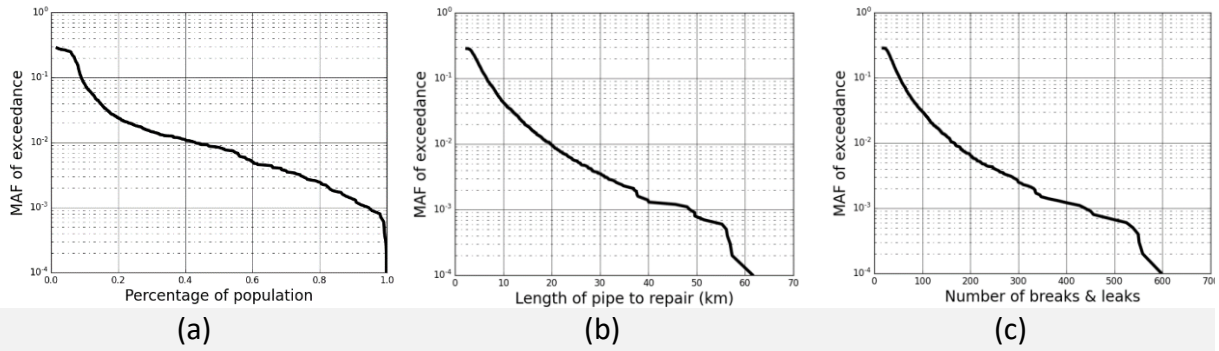
Figure 14: MAF for the water network (a) Percentage of population without access to water, (b) Length of pipe to be repaired (km), (c) Number of breaks and leaks.
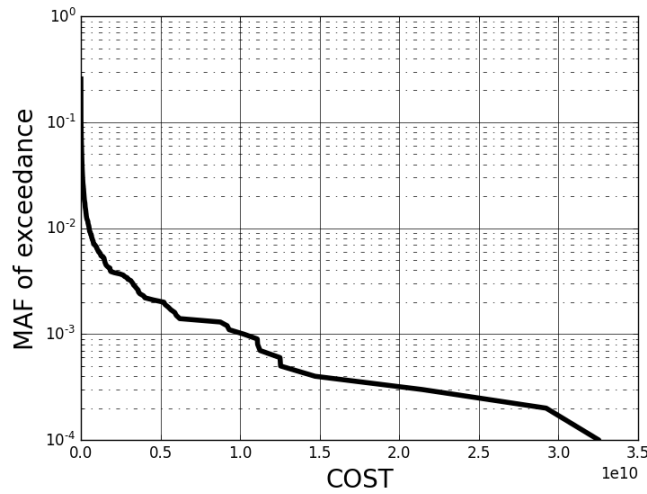
Figure 15: MAF for the Tier 3 buildings.

(a)   (b)   (c)

(d)   (e)
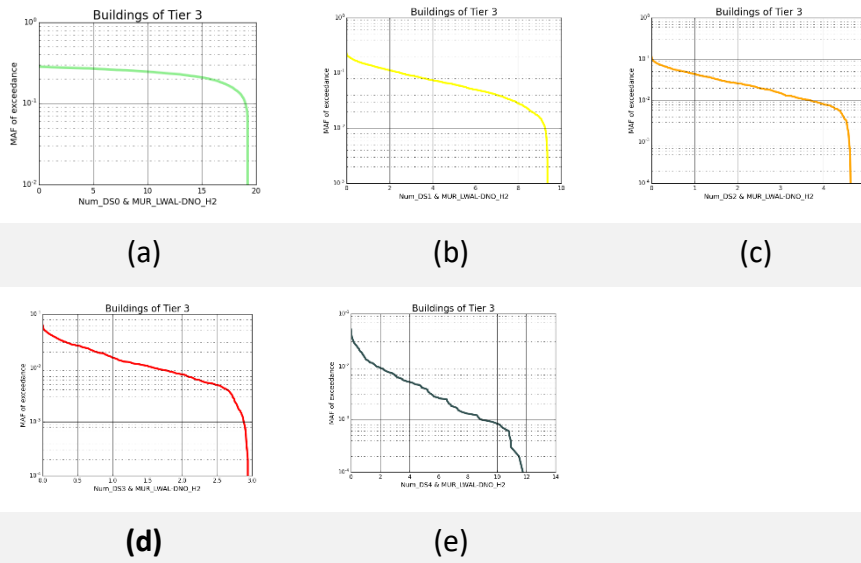
Figure 16: MAF for the Tier 3 buildings per DS and typology (a) DS0: No damage, (b) DS1: slight damage, (c) DS2: Moderate damage, (d) DS3: Extensive damage, (e) DS4: Collapse damage.
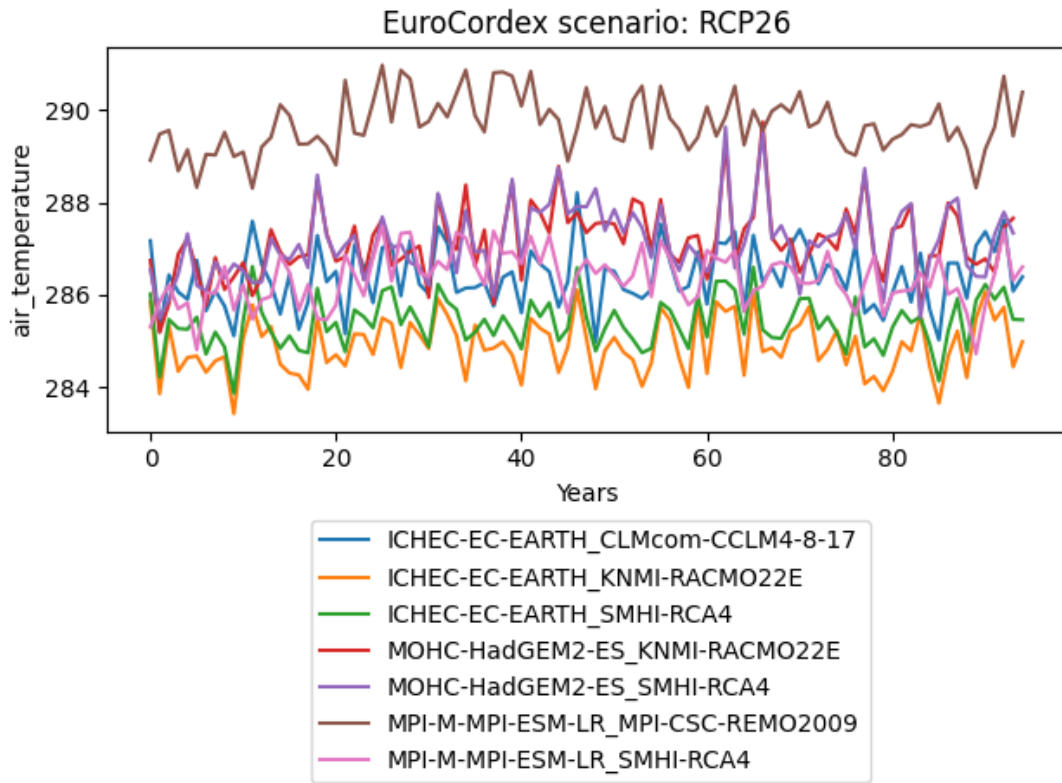
Figure 17: EUROCORDEX results for air temperature for scenario RCP2.6 for Granada, Spain
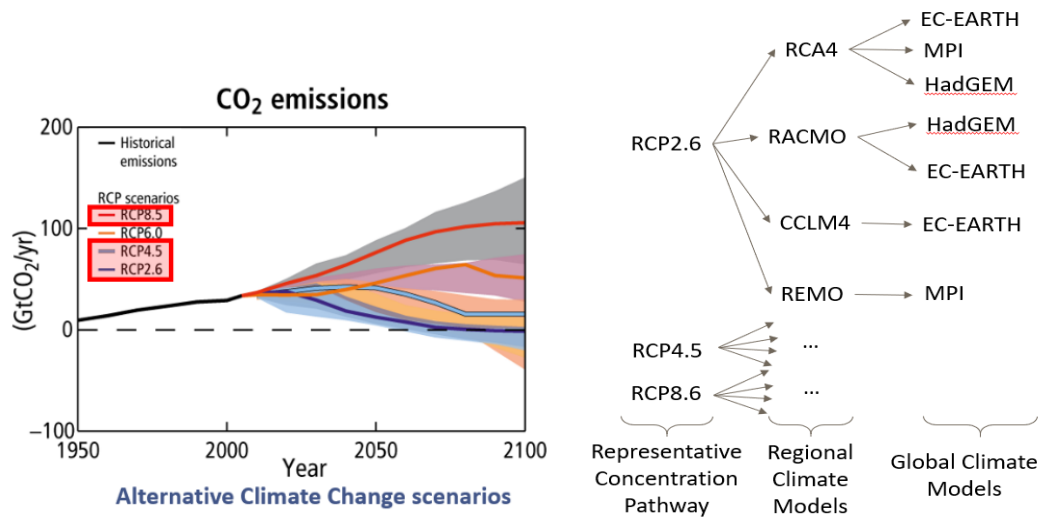
Figure 18: EUROCORDEX scenarios and climate models.

5 Impact Assessment Tool Structure

The HRAP platform consists of 2 main routines that combine the respective inputs to produce the effect for the corresponding hazard on each asset, portfolio of assets, and infrastructure network.

5.1 Software Structure

5.1.1 Impact Assessment – Short term

In order for the Short-Term tool to function, the routine that finds the event of choice must be used. From a list produced from the parameters of choice, one event is picked to use in the main routine that produces the results. This effectively constrains the scenarios shown. The structure of the event filtering routine and the main routine is presented below.

Sub-routine

| FilterEvents.py	Filters the IM field based on defined parameters
o useful_functions.py	Loads and read input parameters then finds the events of interest that corresponds to them
- initialize_files	Initializes the requested files
- load_input_files	Loads the input files and stores the data in variables
- read_inputparamsforfiltering	Reads the input parameters for filtering the events
- filter_events	Finds the events of interest based on hazard magnitude and distance from the source

Main routine

ImpactAssessment_seismic_ShortTerm.py	Short-term seismic impact assessment
o useful_functions.py	Loads and read the inputs as well as the corresponding consequences and plot results
- initialize_files	Initializes the requested files
- read_inputparamsforploting	Reads the parameters that are needed for plotting the events
- load_input_files	Loads the input files and stores the data in variables
- get_imfield_data_event	Filters the data stored in the hdf5 file and keeps only data for the events of interest
- plot_imfield_tiff	Plot the IM field as well as the location of the rupture for the given event ID

- plot_imfield_shapefile	Plot the shapefile for GMF of the given event ID
- plot_cons_shapefile	Plot the shapefile for the consequences of the given event ID
- plot_cons_shapefile_per_ds_and_typ	Plot the shapefile for the given event ID for all or a specific damage states and all or a specific building typology
- get_results_per_ds_and_typ	Get percentage of different typology buildings at the damage stages
- plot_chart_per_ds_and_typ	Maps of buildings per damage state.
- Read_losses_csv	Reads csv of losses
- closest2Tier1	Finds the sid closest the Tier 1
- Fragility	Gives the probability of the Tier 1 of being in each damage state
- makegeojson	Creates geojson file with the Tier 1 coloured based on its DS
- plot_chart_prob_per_DS	Plot chart with the probability of being in each DS

5.1.2 Impact Assessment – Long term

The main routine for the long-term assessment gives aggregated results over all potential scenarios that are produced with the structure presented below.

ImpactAssessment_seismic_LongTerm.py	Long-term seismic & weather impact assessment
o useful_functions.py	Loads and reads the inputs as well as the corresponding consequences and plot results
- initialize_files	Initializes the requested files
- load_input_files	Loads the input files and stores the data in variables
- plot_haz_map_tiff	Plot hazard maps in tiff format
- plot_haz_map_shapefile	Plot the shapefile of hazard map
- plot_cons_figures	Plots and saves loss curves

- plot_eurocordex_figures	Plots and saves figures with climate variables of EuroCordex
- plot_frank_results	Plot weather results for multiple variables based on the Frankenstein methodology
- plot_AAL	Plot the average annual loss graph, direct & indirect
- Plot_fragility	Plot and fragility curves for certain Tier 1 or 2 structures

5.2 Additional supporting functions

Filter Events functions

Function Name	Input
initialize_files	File names, files path
load_input_files	File names
read_inputparamsforfiltering	File names, files path, hazard
filter_events	IM field data, minimum magnitude, maximum magnitude, IM threshold, minimum distance, maximum distance, reference coordinates

Main routine- Short-term

Function Name	Input
initialize_files	File names, files path
read_inputparamsforploting	File names, files path
load_input_files	File names
get_imfield_data_event	IM field data, Event ID of choice, path of file

plot_imfield_tiff	IM field data, Event ID, IM field data of event, hazard, file path, choice of plotting or saving output
plot_imfield_shapefile	IM field data, Event ID, type of asset, hazard, file path, choice of plotting or saving output
plot_cons_shapefile	Type of asset, consequences, Event ID, hazard, file path, choice of plotting or saving output
plot_cons_shapefile_per_ds_and_typ	Type of asset, consequences, Event ID, hazard, file path, choice of plotting or saving output
get_results_per_ds_and_typ	Consequences, Event ID
plot_chart_per_ds_and_typ	Results, labels, Event ID, file path, choice of plotting or saving output
read_losses_csv	File names, event id, files path, choice of plotting or saving output
Fragility	Demo name, a dictionary with the name of the Tier 1 or 2 along the IM point in this event
makegeojson	Demo name, Fragility function results
plot_chart_prob_per_DS	Fragility results, DS category names, results path, chart name, choice of plotting or saving output

Main routine- Long-term

Function Name	Input
initialize_files	File names, files path
load_input_files	File names
plot_haz_map_tiff	Hazard maps, hazard, file path, choice of plotting or saving output
plot_haz_map_shapefile	Hazard maps, hazard, file path, choice of plotting or saving output

plot_cons_figures	Consequences, type of asset, hazard, years, typology, file path, choice of plotting or saving output
plot_AAL	Demo name file path, saving output, result path
PlotFragility	Demo name, result path
make_tiff	Cost per block, result path
plot_eurocordex_figures	Scenarios, models, variables, file path, choice of plotting or saving output
plot_frank_results	Scenarios, models, variables, file path, choice of plotting or saving output

5.3 Data Files

The routines described in Section 5.2 require the appropriate input files to be given so as to be able to function. The data files required for the results along with their characteristics are presented below in Tables 1-4.

Table 1: Data files for Short-term assessment- Filtering seismic Events

Name	Type	Size	Description
input_params_filtering	JSON file	1 KB	The target magnitude and distance range from reference coordinates
filtered_events	Text Document	1 KB	The list of events that fit the parameters
input_params_ploting	JSON file	1 KB	The event id

Table 2: Data files for Short-term assessment- Buildings Tier 3

Name	Type	Size	Description
calc_xx_spCorr	Hdf5 file	~ 2 GB	Ground motion field for all events
Num_DS0-4	PKL file	20-500 MB each	Arrays with the number of buildings per damage state
City_seismic_CityBlocks	JSON file	~200 KB	Exposure of the city

Table 3: Data files for Short-term assessment- Water Network

Name	Type	Size	Description
PGV_spCorr	Hdf5 file	~ 2 GB	Ground motion field for all events
City_exposure_distr_network	JSON file	~ 5 MB	Exposure of the water network
City_exposure_distr_network_mtdata	CSV file	~ 1.5 MB	Exposure model metadata
Percentages	PKL file	~20 MB	The event id

Table 4: Data files for Long-term assessment- Demo name

Name	Type	Size	Description
Exposure_City_num	XLSX file	200-900 MB	Exposure model – Number of buildings per type

Table 5: Data files for Long-term assessment- Buildings Tier 3

Name	Type	Size	Description
City_seismic_CityBlocks	JSON file	~ 10 MB	Exposure model
Num_DS0-4	PKL file	20-500 MB each	Arrays with the number of buildings per damage state
Sum_Buldings_perDS	PKL file	~200 KB	Cumulative number of buildings per damage state
COST	PKL file	500 KB	Dataframe of direct cost per event

hazard_map-mean	CSV file	100 kB	Hazard map for the city

Table 6: Data files for Long-term assessment- EUROCORDEX

Name	Type	Size	Description
Parameter_model_scenario_city	NC file	~ 10 MB	Prediction of variables based on climate change models
Tier1	XLSX file	~ 900 MB	Frankenstein days data

6   Conclusions

The HRAP platform is presented in this accompanying document. With the appropriate selection of models, hazard information, exposure and vulnerability data from previous WPs, HRAP can be a valuable decision support tool for important cultural heritage sites as it offers quick results, through pre-calculated analyses, created for any combination of natural hazard and assets. In this way, users are able to understand the impact of various adaptation strategies and quantify the potential impact of a catastrophic event on society.

7   References

Jacob, D., Petersen, J., Eggert, B. et al. (2014). "EURO-CORDEX: new high-resolution climate change projections for European impact research". Reg Environ Change 14, 563–578. https://doi.org/10.1007/s10113-013-0499-2